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# THE BODY

## AN INTRODUCTION TO PHYSIOLOGY

By

Ronald Campbell Macfie

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# THE BODY

## CHAPTER I

### *INTRODUCTORY*

#### The Nature of Life and Vital Function

> " What a piece of work is man! How noble in reason! how infinite in faculty, in form, in moving, how express and admirable; in action how like an angel! in apprehension how like a god! the beauty of the world! the paragon of animals!"—Shakespeare.

Biologically speaking, the human body is not a thing apart; it is merely a point in the great reticulation of life, a twig on the great family tree of the vertebrates. It confesses distant relationship with the worm, and admits blood relationship with the gorilla. Indeed, it is in intimate inextricable context with the whole material universe. " Putrescent dust of the weary satellite of a dying sun," it still trails clouds of glory from the Milky Way, and its energies, unique in their structural and functional products, are yet *qua* energy merely satellites revolving around infinitesimal suns. All matter is a maelstrom of whirling energy, and the molecules of the human body, though comparatively huge and complex, have precisely the same intrinsic kinetic urge, and the same intra-atomic mainsprings as the molecules of chalk or cheese. In fact, the human body is just a physico-chemical phenomenon in a physico-chemical world, and its embryogeny, structure, and functions might be expressed—to some extent

at least—in complicated chemical formulæ and equations.

On this point the verdict of science is unequivocal and categorical. Science maintains that living organisms are chemical products of warm mud and atmospheric gases, that when the crust of the cooling and sterile earth attained a suitable temperature, atoms of carbon, hydrogen, oxygen, and nitrogen combined, under the ordinary laws of chemical affinity, to form gigantic molecules of the vital substance " protoplasm "—" a self-generating reproductive carbonaceous jelly " whose complicated chemical constituents, reacting *inter se,* and with their environment, give rise to metabolism, assimilation, reproduction, and the other functions called 'vital' by which we define living things. This " primordial flux " and its results were due simply to chemical affinity and chemical combinations, with consequent chemical processes in a complex matrix set in a complex and variable environment. A wonderful flux, certainly; but " who," asks Tyndall, " will set limits to the possible play of molecules in a cooling planet?"

According to this theory, the first little speck of protoplasm was chemically constituted in such a way that it not merely multiplied by division or budding, but coincidently varied and mutated, so that eventually, by selection of variants and mutations, various species of unicellular organisms came into being. In time were evolved variant cells, whose buds—arranged in certain definite orientation and form—maintained chemical and structural connection with each other, and became lowly multicellular organisms; and finally the germ-cells of these lowly multicellular organisms evolved, by a process of variation and selection, into the wonderful ovum of man. Heredity, evolution, and variation led to man, and still to-day in man and in all living beings we see reproduction, variation, and evolution at play.

That is the commonly held scientific theory of the evolution of living organisms. It implies that man's body is as much a chemical product as salt, that the functions of his body are as chemical and mechanical as a gunpowder explosion. Nevertheless, there are, perhaps, some qualifications that may be made.

It is impossible to believe that *all* the motor processes that take place in man are purely chemico-physical, for though Shakespeare's fingers when he wrote his plays, Newton's fingers when he wrote his *Principia,* derived their energy from chemico-physical sources, yet they moved in such ways, and to such purpose, that no purely chemical explanation can be entertained by any reasonable man.

We cannot, it is true, get away from the law of conservation of energy; and the energy in the writing fingers and in the bustling brain-cells is indubitably physico-chemical, and precisely of the same nature as the ordinary protæan energy which we know in interchangeable forms as heat, electricity, motion; but nevertheless, even in the face of these facts, it is quite legitimate to maintain that in certain entities the energy is used and directed by a mysterious *something* which we may call "prescient volition."

There certainly seems, in most of the characteristic processes of life, something of the nature of conation or volition—what Karl Baer called "effort towards a goal." They work in a co-ordinated way towards a useful end, much in the way we work when we perform voluntary and useful actions—a way in which dead matter (therefore called dead) never works.

When we talk of volition as a factor in vital actions, we get on rather dangerous and controversial ground, and in this little book such ground must be avoided; but the idea of volition is inevitable, for it is imported into physiology the very moment we talk of *voluntary* muscles, and by Huxley's own admission "our volition counts for something in the progress of events."

It is true that chemists have succeeded in forming many of the carbon compounds which otherwise occur only in the tissues of living organisms or as a product of their metabolism. As long ago as 1828, Woehler made urea in his laboratory; in the beginning of this century Emil Fischer of Berlin succeeded in making polypeptides—a step towards the proteins of protoplasm—while within recent years it has been found by Bayly and others that ultra-violet, with the assistance of longer rays, can produce in a solution of carbon dioxide a sugar which is at once a building stone and a fuel in the processes of life. But between producing the substances that are found in living tissues and producing the organised self-multiplying unit—the living cell—there is a great gulf fixed, and no living organism has ever been produced save by a precedent living organism.

We may, if we will, regard the body as a machine in the fullest Cartesian sense, but every machine is a mento-volitional product, and most machines when made require a mind to use them. If there is nothing more than physio-chemical processes behind the building-up and behaviour of living things, then, as said Sir Thomas Browne, "let our hammers rise up and boast they have built our houses, and our pens receive the honour of our writing."

It is, in fact, impossible completely to explain all vital processes by reference to physico-chemical processes, and there is at least logical probability that volitional or quasi-volitional processes led from the amœba to the mammal, and from the tracks of the annelids in the Silurian clay to the script of Shakespeare and the symbols of Newton; and, indeed, we may almost define physiological functions as actions occurring in matter which seem to require some volitional guidance, even although, as we have said, the energies at the back of the activities of living things and many of the activities themselves can be explained

by reference to ordinary mechanical and physical principles which it is the work—perhaps the main work—of physiology to discover.

The physical basis of all vital or physiological functions—of everything that happens in so-called living organisms—is protoplasm, a colloid (gum-like) substance consisting mainly of carbon, hydrogen, oxygen, nitrogen, phosphorus, and water. Of this "enchanted dust," every living thing is built—roses and reptiles, starfish and men. Its constituents are plainly ubiquitous and commonplace. Carbon is found in coal, graphite, diamonds, and carbon dioxide. Oxygen and nitrogen are found in the atmosphere. Hydrogen is found wedded with oxygen in water. Sulphur and phosphorus are found in volcanoes. In fact, in an ordinary lucifer match there is every element essential for life.

In the body of a woman of average size there are nine gallons of water; enough oxygen to fill eight hundred nine-gallon barrels; enough carbon to make nine thousand graphite pencils; enough phosphorus to make eight thousand boxes of matches; enough hydrogen to inflate a balloon capable of raising the whole body to the top of Snowdon; enough iron to make five tacks; enough salt to fill six ordinary salt-cellars; and four or five pounds of nitrogen. "A few gallons of water," writes Oliver Wendell Holmes, "a few pounds of carbon and lime, some cubic feet of air, an ounce or two of phosphorus, a few drams of iron, a dash of common salt, a pinch or two of sulphur, a grain or more of each of several hardly essential ingredients, and we have man according to Berzelius and Liebig."

Till the nineteenth century the human body was regarded as built up of a slimy and gelatinous fluid; but in the middle of the nineteenth century Schwann and Virchow demonstrated that protoplasm of the tissues of the higher animals and plants is "done up" in tiny packages or "cells," and that the life of the

animal or plant is a summation of the processes occurring in the individual cell.

The cell is, indeed, the unit of all vital function: each cell is able to assimilate, and grow, and at some time to reproduce itself, and, as in the case of the amœba, a single cell may form a complete self-contained organism.

Man himself begins as a single cell—the fertilised ovum—but this single cell develops by a process of budding into a great colony or commonwealth of co-operative cells whose activities are marvellously co-ordinated for their mutual advantage. The cell grows, buds, multiplies, mutates. Cell is cunningly plastered to cell and fibre wonderfully interwoven with fibre till there are eyes and mouth and nose, till a little red point becomes a beating heart, till the thing can breathe and digest and walk and talk and think. From one invisible cell has been built and woven the multifarious tissues and organs of a man.

As the cell buds, its progeny of buds varies, and cells of various shapes and kinds come into being and play particular parts in the structure and functions of the body. Over the surface of the body is the marvellous tessellated tissue—the skin—forming a rain-proof panoply as soft as silk, yet more durable than armour. The surface of the air-tubes is lined with cubical cells like bricks set on end in close juxtaposition, and each cell bears little hair-like appendages, which jut into the tubes and, lashing to and fro, protect the lungs from foreign particles. Over the surface of the brain, again, is a layer of spidery or starry cells—the wonderful cerebral cells, which are the centres of sensation, movement, and thought. Some of these cerebral cells send prolongations, the "axis cylinders," down to other cells in the spinal marrow, and these cells in turn send forth prolongations which form nerves of sensation and nutrition and motion. In the blood swarm millions of free cells

—the white and red corpuscles, which carry roving commissions.

By combinations of various cells the so-called organs of the body—the heart, lungs, liver, etc.—are built up, while the form of the body is conserved, and its motions in space facilitated by a framework of lime—the bones.

Every cell in this marvellous cellular agglomeration is the seat of complicated chemical reactions; its substance, semi-liquid and colloid in nature, is constantly breaking down and being built up again, probably by processes and according to laws purely physico-chemical; and with these reactions the great processes of reproduction and special adaptive movements are in some way correlated.

Growth (in the organic sense), reproduction, and special adaptive movements do not follow the chemical changes which occur in most forms of matter, and it is these phenomena which are taken to distinguish living from dead matter, and it is with these and their physico-chemical causes or concomitants that physiology is concerned. Physiology endeavours so far as possible to explain the functions of the body by reference to the simple chemical and physical reactions that take place in matter which does not show the special vital processes, and it has at least succeeded in showing that *many* of the events that occur in the body connected, and perhaps causally connected, with reproduction, purposive movement, etc., can be imitated in a test-tube without the intervention of any driving or directive force other than the forces of chemical combination that caused heat and movement in so-called "dead" matter. It has succeeded to that extent, and it has also succeeded in demonstrating that the energy of the body is of the same nature as the energy that works in dead matter, but it has not yet succeeded in producing by chemical means those special great co-ordinated complexes of adaptive energy which we

specially associate with life, and there is still, therefore, room for believing in the possibility of some factor like volition.

If physiologists and chemists ever succeed in reproducing *all* the phenomena of life, including reproduction and purposive behaviour, to purely chemico-physical reactions, then physiology as a science will cease to have a separate existence, and will become merely a department of chemistry and physics.

Three great independent discoveries may be said to be the fundaments of modern physiology: (*a*) the discovery of the heart's action by Harvey in 1628; (*b*) Lavoisier's discovery in 1777 of the part played by oxygen in respiration; (*c*) Schwann's and Virchow's demonstration, in 1839, and 1856, of the multicellular construction of the higher plants and animals.

Without these three fundamental discoveries any chemico-physical analysis and chemico-physical theory of the processes and activities exhibited by the human body would have been impossible, and to them modern physiology owes what successes it has won in the reduction of the vital functions to ordinary physical and chemical actions and reactions.

# CHAPTER II

## *THE DIGESTIVE FUNCTIONS*

"The health of the whole body is tempered in the laboratory of the stomach."—Don Quixote.

Perhaps the most fundamental of the bodily functions are the functions of digestion.

The living cell is the seat of multifarious and complicated chemical processes—fermentations, oxidations, etc.—which result in a constant breaking down (katabolism) and building up again (anabolism) of its substance. These chemical processes maintain the cell's structural characters, generate heat, and are frequently associated with growth, reproduction, and molar motions. They consist not so much of reactions between the chemical constituents of the cell, as of reactions between the cellular constituents of the cell and their environment.

The chemistry of life is cosmic as well as protoplasmic, and the cells of the body derive most of their energy from extraneous sources—proximately from food and breath, and ultimately from the sun and atmosphere. Without extraneous chemical intervention and provocation, protoplasm cannot long maintain active energy, and could never exhibit the larger manifestations of life.

The most radical reactions between protoplasm and its environment are seen in the so-called "digestive processes"—in other words, in the reactions between the cell and its food. Food provides both building material and energy, and without food the cell has neither material nor energy to carry on its vital functions.

The wonderful cell, the fertilised human ovum, like all other single and unassociated cells, obtains food-material directly from its environment—from the maternal serum—and its whole surface ingests the material, and prepares it for building purposes. But when, as the result of superabundance of energy and material acquired from the mother's blood, the cell buds and multiplies to form a mass of millions of closely-packed cells, the feeding facilities are restricted, and it becomes necessary to have a special commissariat department and to devise means of access, distribution, and transport. Accordingly in the completed organism we have the elaborate digestive apparatus—mouth, gullet, stomach, intestine, and associated glands, with ancillary apparatus in the heart, bloodvessels, nerves, etc.

The food-material used by man does not come to him as it came to the ovum: he has to collect it with his hands and pass it via his mouth, and intestines, and lymphatics,* and bloodvessels, to the multitudinous cells of the body.

The so-called "digestive apparatus" receives the food-material, kneads it, chemically treats it, and passes it on to the cells of the body in an altered form suitable for use. It consists of an orifice, the mouth, which is situated under the eyes and nose, and is furnished with grasping, grinding, and tearing tools of hard lime—the teeth. From the back of the mouth cavity proceeds a long narrow tube, the "gullet" or "œsophagus," which is about a foot in length, and expands into the muscular sac known as the "stomach." From the stomach proceeds another much-looped tube some three yards in length, which again

* The lymphatics are fine tubules filled with a fluid-like colourless blood. They carry waste products and food.

is continued as a shorter, wider tube, the large intestine, which ends at the rectal orifice. The food entering at the mouth is propelled by muscular action along the whole length of this crooked tract, and, as it moves along, is subjected to various chemical processes. Before, however, we discuss these chemical processes we must know something about the nature of the wonderful food-substances which bring energy and building material to the cell.

Chemically speaking, there are two main classes of food-stuffs (stuffs which when brought into contact with living cells build up and energise them)—those composed of carbon, hydrogen, and oxygen, and those composed of carbon, hydrogen, oxygen, and nitrogen. In the first class are the so-called "carbohydrates," sugar and starch: in the second class are the so-called "proteins." Fatty foods are to hand in such forms as butter, cream, olive-oil; sugar is found in the form of glucose, and fruit sugar, and honey; starch is found almost in a pure form in polished rice, and in bananas; protein is found in almost a pure form in the white of egg, lean meat, and fish, and milk cheese.

The carbon, hydrogen, oxygen, and nitrogen of which we have said protoplasm is mainly composed can be obtained, and are usually obtained, by the living cells of the body from the carbon, hydrogen, oxygen, and nitrogen of the fats, carbohydrates, and proteins of a mixed diet, but since protein, as we have mentioned, contains all four essential elementa, a pure protein can, if need be, supply all the building and repairing and fuel materials that the cells require.

All the food-substances in both classes are of animal or vegetable origin, and all contain latent chemical energy ultimately derived from the energy of the sun, and it is this latent chemical energy that is utilised by the cells of the body for building and working pur-

poses. In the last resort, living bodies are essentially sun machines.

The latent energy supplied to the body by various food-substances can be estimated by burning the food and measuring the amount of heat or caloric energy evolved during combustion. The unit of heat chosen as a standard of measurement is the calorie—*i.e.,* the amount of heat required to raise the temperature of 1 lb. of water 4° F.; and this in terms of work is about equivalent to the work performed in raising one ton a foot and a half, or in raising a ton and a half one foot.

Measuring, then, in calories, the energy provided by various forms of food, we find that the combustion of one gram (about $\frac{1}{28}$ of an ounce) of carbohydrate or protein will produce about 4·1 calories of heat, while the combustion of one gram of fat will produce about 9·3 calories, the amount varying slightly according to the precise chemical character of the carbohydrate, protein, or fat which is burned.

The caloric or energy-value of protein and carbohydrate is about 116 calories per ounce, and of fat 263 calories per ounce, and these substances, taken as food, are capable of supplying the body with equivalent amounts of heat or of mechanical energy—assuming, of course, that all the food, in each case, is completely assimilated.

The amount of calories required to keep a human being alive, and warm, and energetic, varies with the size, build, age, health, work, sex. A minimum subsistence diet is usually fixed at 2,000 calories; 3,000 calories are enough for an average man doing ordinary work; the field ration of the British soldier is 4,600 calories; while a man doing very hard work may require even more to maintain equilibrium. The following standards give some idea of normal variations:

RUBNER'S STANDARD

| | Calories. |
|---|---|
| Rest, *e.g.*, clerk at a desk ... ... | 2.500 |
| Professional work, *e.g.*, a doctor ... ... | 2,631 |
| Moderate muscular work, *e.g.*, a house painter | 3,121 |
| Severe muscular labour, *e.g.*, a shoe-maker ... | 3,659 |
| Hard labour, *e.g.*, blacksmith or navvy ... | 5,213 |

ATWATER'S STANDARD

| | Calories. |
|---|---|
| Man without muscular work ... ... | 2,700 |
| Man with light muscular work ... ... | 3,000 |
| Man with moderate muscular work ... | 3,500 |
| Man with severe muscular work ... ... | 4,500 |

The calories required to provide energy may be given exclusively in the form of protein, or of starch, or of sugar, or of fat; but if they be given as starch, or sugar, or fat, at least two ounces of protein must be added to provide nitrogen for the building up of the tissues, for nitrogen the tissues *must* have.

As a rule, a mixed diet is best, and the diet of the average man consists of protein, and fat, and starch, and sugar, and about twice as much protein as is required for building purposes is usually taken. If protein alone be given, one would require to take about eight pounds of lean meat, or fifty or sixty eggs daily, and not only would the diet be expensive, but appetite would fail, and the digestion would rebel. Also if energy were supplied solely in the form of sugar, or of starch, or of fat, there would be digestive troubles. A diet, on the other hand, containing 118 grams of protein, 56 grams of fat, and 500 grams of carbohydrate would be a well-balanced diet, and would provide about 3,000 calories for heating, building, and working purposes.

It must be noted that in an adult man only a small

proportion of the caloric energy of his food is at the disposal of his voluntary muscles, for much the greater part of available energy is utilised in keeping the body warm and in working the circulatory and respiratory organs.

The foods, however, which supply energy to the body are not usually available as sources of energy until they have been prepared by certain chemical and mechanical processes which operate, as we have already said, along the whole length of the digestive canal.

In the mouth the food is mixed with saliva, and, if solid, is torn and cut, and crushed by the teeth. The saliva (secreted by six glands*) not only moistens the food and facilitates swallowing, but, by means of a ferment called *ptyalin,* splits starch into *dextrin* and *maltose.* Every day the salivary glands pour out about two pints of saliva into a man's mouth. The outflow is excited by the nerves of taste, sight, and smell, and increases if the food be dry.

The food, when thus insalivated and altered, is swallowed, and carefully steered past the larynx and the posterior orifice of the nose, passes down the gullet into the stomach.

The stomach is essentially a muscular bag lined with mucous membrane. Some of its muscular fibres are arranged circularly, some longitudinally, and some obliquely, and, by contraction and relaxations of its various fibres, the food in the stomach is squeezed and churned. The stomach pushes on its contents by alternately contracting and relaxing in its lower part wave

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* A gland is defined by Sir Arthur Keith as "any organ whose function it is to manufacture some special product and liberate it for the benefit of the body as a whole." The substance formed is called a secretion, and when the gland liberates the product it is said to secrete it.

after wave; each ring of contraction forcing the semi-liquid food forward towards the intestine. There is a constant succession of contraction and relaxation waves, and as many as three may be seen in progress at the same moment. The contracting muscles usually contract at a rate of three contractions every minute, but sometimes as fast as six contractions a minute.

The stomach-sac is lined with a sort of pavement of delicate cells, which constantly secrete a lubricating and cleansing fluid, the *mucus;* its muscular walls are richly supplied with blood by a close meshwork of tiny bloodvessels (*capillaries*). In the walls, too, is another system of fine tubules called the *lacteals,* filled during digestion with a milky fluid (the *chyle*), which they pour into the large veins near the heart. The stomach, too, is richly supplied with nerves—some coming from the top of the spinal cord and some from the middle. These are wires for messages to and from the stomach.

The mucous membrane which lines the sac is pitted with little depressions, and in the depressions are the orifices of glands—the *gastric glands*—which pour a digestive fluid known as the *gastric juice* into the cavity of the stomach. In the gastric juice is hydrochloric acid, together with three ferments named *pepsin, lipase,* and *rennin,* and the acid and the ferments all act upon the food. The acid kills many of the micro-organisms that may occur in food, and changes cane sugar into the sugar *dextrose* and *lævulose*. The acid and the pepsin, acting together, change food proteins which are insoluble into soluble substances called *peptones*. The lipase splits fat into glycerine and fatty acid. The rennin curdles milk. Of these actions the action of the pepsin on the protein is the most important. The main use of the stomach is to render soluble and fit for absorption such protein foods as meat, eggs, fish, milk, oysters.

The outflow of gastric juice, like the outflow of

saliva, is to a great extent under the control of the nerves of sight, taste, and smell; and it is important, therefore, if digestion is to proceed satisfactorily, that food should be pleasant to look upon, and tasty, and of good odour. The juice joured out on excitation of these nerves is called *"psychic"* juice or "appetite" juice.

After the food has reached the stomach this further juice is excited in the stomach by the presence of the food, the amount of outflow depending on the nature of the food. White of egg and bread excite no secretion; while meat extracts, and milk, and dextrin provoke a good flow. The flow is caused by a chemical stimulation of the glands of the stomach through the absorption of one of the first products of digestion, a substance called "glandin"; and so the adage that appetite follows eating has truth in it, and the habit of starting dinner with meat extract soups is seen to be physiologically correct.

Fluid or semi-fluid food passes quickly through the stomach, and some sugars and salts and poisons are absorbed *en route*. Food of greater consistence, however, remains for some hours undergoing a digestive and softening process. Usually the stomach has passed all its contents on to the small intestine within three or four hours, but food difficult of digestion, such as plum-pudding, may remain twice as long.

As soon as the food from the stomach (called after gastric digestion *chyme*) reaches the small intestine, it is acted upon by the *pancreatic juice*—a juice secreted by a large glandular organ, the *pancreas,* and poured through a little tube or duct into the small intestine at its beginning, *pylorus.*

The outflow of this juice in the right amount at the right moment is achieved in an interesting automatic way. When the acid chyme passes into the small intestine, it causes the cells lining the pylorus to secrete a ferment called *secretin,* and this is carried

by the blood to the pancreas, and there stimulates the outflow of pancreatic juice. But the pancreatic juice is alkaline, and its alkalinity neutralises the acidity of the chyme, and so no more secretion is formed, and therefore no more pancreatic juice is secreted till a new gush of acid chyme again forms secretin, and again provokes the outflow of the juice.

The pancreatic juice is the most potent of all the digestive juices: it is more potent than the gastric juice, for it acts upon starch as well as upon fats and proteins. In fact, it exerts a threefold action: it converts starchy foods into the sugar called *glucose;* it breaks up fat into glycerine and a fatty acid; and it splits the peptones formed in the stomach into fragments known as *amino-acids,* and itself makes peptones out of protein and breaks them up. It must be noticed, however, that the pancreatic juice is able to split proteins and peptones into amino-acids only after it has been acted upon by a substance secreted by the small intestine called *entero-kinase,* which converts a substance *trypsinogen* in the pancreatic juice into another substance *trypsin,* which is the active agent in the splitting up of the protein.

Besides entero-kinase, the juice of the small intestine contains substances which act on sugars and a substance *erepsin,* which splits peptones and other products of protein digestion. In young children there is also a substance which acts on milk.

The large intestine has little or no digestive action.

The main purpose of the processes in the alimentary canal is to render the food absorbable, and the net result is a conversion of carbohydrates into sugar, of proteins into amino-acids, and of fats into fatty acids and glycerine. But digestion in the full sense of the term only begins with these conversions, the substances have to be absorbed, and during the time that the digestive products are propelled along the gastro-intestinal tract by circular and longitudinal muscle

fibres in its walls, absorption is actively taking place.

The products of digestion are picked up by the cells which line the digestive tract, and these cells pick up and select the food-products in a way not fully understood, and pass them on to the bloodvessels and lacteals in their vicinity, whence they are carried to the liver, where they undergo further preparatory processes. Generally speaking, the protein and carbohydrate products are absorbed by the bloodvessels and the fats by the lacteals.

Practically no absorption takes place in the mouth and gullet, and very little in the stomach: the main site of absorption is the mucous membrane of the small intestine, which is thrown into folds and covered with little projections, "villi," like the pile of velvet, to increase its surface. The villi number 10,000 to the square inch, and the villi and folds of the small intestine together offer an absorbing surface of no less than fifty square yards, and over this large surface glucose and amino-acids are vigorously absorbed. The absorption is the work of the special cells with which the intestine is lined, and so far it cannot be entirely explained by reference to chemical and physical principles.

The carbohydrates of the food enter the blood as glucose, and the glucose is carried by the blood to the liver, where it is converted into glycogen, and stored up for after use. The various proteins of the food enter the blood in the fragmentary condition of amino-acids, and some of the fragments are built up again into proteins, while some are broken down still further into urea. For years chemists have been trying to imitate this process and to break down proteins into amino-acids, and then build them up again into proteins; but so far no one has succeeded, though Emil Fischer, the famous Berlin chemist, has succeeded in making polypeptides out of amino-acids, and polypeptides are a step toward proteins.

The fats in the food are absorbed in the form of glycerine and fatty acids by the *lacteals,* which run in the centre of the villi of the small intestine, and in the cells that cover the villi they are built up into fat again. Eventually the fat droplets flow into the great lymphatic vessel, the *thoracic duct,* and through it reach the blood. From the blood the fat is collected by the cells of adipose tissue and serves as a source of heat and muscular energy, and it is also probably incorporated in living cells in the shape of lecithin.

Carbohydrates, proteins, and fats, then, are the main materials in the cell's environment, which react with it and enable it to build up its substance, to grow, to produce heat, to perform various mechanical and chemical functions; but besides these main materials, other subsidiary materials are essential for vital processes. Water is, of course, necessary, and also certain mineral salts dissolved in the water. The salts are incombustible, and can be only indirectly a source of energy, yet they are necessary, and lacking all salts or even one important salt, such as common salt, an animal dies in less than a month. In the absence of common salt, gastric juice loses its potency. Bones cannot be formed without lime. The red blood corpuscles need iron, the muscles need potassium phosphite. Nerve tissue is rich in phosphorus. Man's ancestor probably was a cell living in sea-water, and still the blood of man contains mineral salts resembling the salts contained in sea-water, and these are necessary for healthy structure and function.

Also necessary for healthy structure and function are the substances called *vitamins*—substances which are found in very small quantities in food, and which in rather mysterious ways regulate nutrition, growth, and vigour. Vitamins were unknown and unsurmised till it was discovered that beri-beri was due to lack of some substance present in the husk or pericarp of rice. That discovery led to the discovery that some other

diseases, such as scurvy and rickets, were due to lack of similar substances. The vitamin which assists in bone formation and which prevents rickets is found not only in certain foods, such as milk and cod-liver oil, but is formed in the skin under the action of the ultra-violet rays.

The relation between food and the vital structure and vital functions of man and other animals is very remarkable. It is very remarkable how the food substances are altered and prepared for use in the gastro-intestinal canal and liver, and both remarkable and mysterious are the further processes by which the products of digestion are absorbed and built up into the living tissues. A great part of the life of the body is a matter of reactions between its cells and the items of their environment, which are called food.

# CHAPTER III

## *THE HEART, BLOOD, AND CIRCULATION*

"'True it is' (quoth the belly)
'That I receive the general food at first,
Which you do live upon; and fit it is
Because I am the storehouse and the shop
Of the whole body: but if you do remember
I send it through the rivers of your blood,
Even to the court, the heart—to the seat o'
the brain,
And through the cranks and offices of man,
The strongest nerves and small inferior veins,
From me receive that natural competency
Whereby they live.'"

CORIOLANUS.

THE heart is a marvellous bag woven of muscle fibres. It is constructed on the principle of a force pump, and by a process of alternate contraction and relaxation of its muscle fibres, and with the assistance of suitable valves, it drives the blood along a series of close tubes and tubules, the arteries,* and veins, and capillaries, and, through the thin-walled capillaries, distributes to every cell in the body the food products provided by the liver and gastro-intestinal tract. Further, as the

* The arteries are strong, thick-walled tubes which carry the blood in an outward direction from the heart to the body: the veins are weaker tubes with thinner walls which carry the blood in a direction towards the heart; capillaries are microscopic tubules, arranged usually in a fine network, which intervene between the arteries and the veins.

blood, in the course of its circulation, is driven through the lungs, oxygen from the inspired air is collected by the red blood corpuscles, and these corpuscles, carried along in the current of the blood, give the oxygen to the body cells, and so supply them with chemical energy available for the vital functions. These are the main offices of the heart—to supply the cells with food products prepared by the digestive organs and to supply them with oxygen collected from the air by the red blood corpuscles. But it also drives along the waste products formed in the katabolic processes of the body and facilitates their removal or utilisation. When the heart beats too feebly the other vital energies flag, when it ceases to beat they quickly fail altogether.

It is strange to think that up to the seventeenth century the function of the heart was misunderstood and its beatings misinterpreted. Till Harvey elucidated the problem in 1628 there prevailed quite erroneous conceptions of the work of the heart, such as the theory of his great master Fabricius. Fabricius, following Aristotle and Galen, taught that "nutritive" blood formed by the stomach was transformed into "real" blood by the liver—that the real blood flowed into the right ventricle and oozed through the intervening wall into the left ventricle, where it was mixed with air received directly from the lungs and became vital spirits. The left ventricle was, therefore, merely a vat where vital spirits were brewed. He taught, further, that the arteries expanded and sucked the vitalised blood into the tissues where they were laden with fuliginous vapours, and that thereafter the arteries contracted and forced the blood back to the heart again. Circulation on this theory was simply an ebb and flow—an idea evidently in Shakespeare's mind when he wrote, "Dear to me are the ruddy drops that *visit* this sad heart," and in Milton's when he described Eve's "ampler spirits and dilated heart."

While such ingenious but erroneous theories pre-

vailed, a sound conception of the functions of the body could not exist, and Harvey's discovery, as we have already said, is one of the foundation stones of modern physiology.

As elucidated by Harvey, the action of the heart is simple.

The heart sac is pear-shaped, and is divided by a longitudinal partition or "septum" into a right and a left half—the two halves quite self-contained like semi-detached houses—and each half again is divided by a transverse partition into upper and lower inter-communicating chambers. In the case of the right half the upper smaller chamber is called the "right auricle" and the lower larger chamber the "right ventricle," while in the case of the left half the upper smaller chamber is called the "left auricle" and the lower larger chamber the "left ventricle." The openings between the right auricle and ventricle and between the left auricle and ventricle are guarded by valves.

Each half of the heart may be regarded as a force pump; but the main propelling force is the muscular wall of the comparatively thick left ventricle. When the powerful muscles of this chamber contract they drive the blood through a valvular opening into a large bloodvessel called the "aorta" and into the hundreds of smaller vessels into which the aorta divides and subdivides, and by a repetition of contractions forces it along ounce by ounce. All the blood impelled in this way is finally forced through the capillaries into the veins and via the veins and the right auricle finally reaches the right ventricle. The right ventricle in turn contracts on its quantum of blood (which, in the course of its circulation in the capillaries, has given up most of its oxygen to the cells) and forces it through a bloodvessel called the pulmonary artery to the lungs and through the capillaries of the lungs back *via* the right auricle to the

left ventricle. *En route,* in the capillaries of the gastro-intestinal tract and liver, the blood takes up food products, and in the capillaries of the lungs it takes up fresh oxygen, so that when it arrives in the left ventricle it is rich both in food products and in oxygen, and carries a store of nutriment and energy for the cells of the body.

The work of the heart is aided and directed by valves, and it was, indeed, chiefly a study of the valves of the heart that led Harvey to his epoch-making discoveries.

Here we cannot deal with the valves in detail, but a brief statement may be made. The orifice, which leads from the left ventricle into the aorta, is supplied with a valve constructed in such a way that it permits blood to flow into the aorta but, if it is sound, does not allow the blood to flow back again into the ventricle. When the left ventricle has driven its bagful of blood into the aorta, the back pressure closes the valve, and its closing can be heard as a click. Also, the orifice that leads from the right ventricle into the pulmonary artery (which conveys the blood to the lungs) is provided with a valve which, if sound, allows the blood to go to the lungs under pressure of the right ventricle and prevents all regurgitation from the pulmonary artery into the ventricle. The aurifices, again, between the auricles and ventricles are guarded by valves which allow the blood to flow from the auricles to the ventricles but not from the ventricles to the auricles. In this way, when the valves are sound, the blood can flow in one and only one direction. In cases of valvular disease, however, when the valves are thickened or distorted, blood can leak back in the wrong direction through the valves, and the heart pump becomes inefficient.

The valves have two or three cusps each and are usually beautifully efficient in their working, and the cusps of the valves between the auricles and ventricles

are strengthened by little tendinous strings which run from the cusps' margins to little nipple-like muscles projecting from the walls of the ventricles. These strings pull on the edges of the cusps and prevent them from being turned inside out by the pressure of the blood in the contracting ventricles.

The bloodvessels have elastic and muscular tissues in their walls, and the work of the heart is assisted by the contractile force of the bloodvessels, which not only aids in driving the blood onward but steadies the blood pressure. The musculo-elastic tubing of the arteries, indeed, makes the blood flow steadily from ventricle to ventricle, much as a steady spray can be made to come through a nozzle by pressure produced by means of an elastic-valved bulb and piece of elastic tubing, and when, in old age, the arteries lose their elasticity the work of the heart becomes much harder. The flow of the blood is also aided by the suction of the expanding chest and expanding right ventricle and by the compression of various contracting muscles.

The left ventricle, as we have said, forces the blood, in the first instance, into the large arterial vessel, the aorta, and the aorta divides and subdivides, giving off branches that extend through the whole body. The total cross-section of the branches into which the aorta primarily divides is vastly greater than the cross-section of the aorta itself, and as branches multiply the disparity increases, so that ultimately if all the capillaries were made into one tube it would have a diameter hundreds of times the diameter of the aorta. In aggregate length the capillaries stretch for thousands of miles; the capillaries of the lungs alone, if made into one straight tube, would reach across the Atlantic. In these fine tubules there is a constant leakage of blood with nutrient contents to the tissues, and a constant passage of waste materials from the tissues to the blood, and the length, together with the large cross-section of the tiny tubules, offers a larger surface

for this interchange, and, by slowing the blood current, gives longer time for the interchange to be effected. In the aorta, the blood on the average flows at the rate of about 60 feet a minute, while in the capillaries it is slowed down to one inch per minute. By taking a short circuit through the carotid artery and veins to the heart, a drop of blood can perform a circuit in 15 seconds, but, as we have said, there are thousands of miles of capillaries and a drop can make circuits of varying length at various rates. On the average, a drop of blood goes nearly a mile a day or 365 miles a year, or over 25,000 miles—more than once round the world—in a lifetime of seventy years; but its flowing performances naturally depend on the strength and activity of the heart.

The contractility of the heart resides in the muscular tissue itself, and the heart begins to beat when it is microscopically small and long before the nervous system is in being. Harvey tells how he saw the new-born heart beating in the embryo chick: "I have also observed," he says, "the first rudiments of the chick in the course of the fourth or fifth day of incubation in the guise of a little cloud, the shell having been removed and the egg immersed in clear, tepid water. In the middle of the cloudlet in question there was a little bloody point so small that it disappeared during the contraction and escaped the sight, but in the relaxation it reappeared again, red and like the point of a pin; so that betwixt the visible and invisible, betwixt being and not-being, as it were, it gave by its pulses a kind of representation of the commencement of life."

A little bloody point like the point of a pin, glowing like a red star in a cloud, blossoming and fading away, that is how the proud heart of man begins, but no movement in the universe, not the whirling of a sun, not the bourgeoning of a nebula, is so wonderful as the rhythmical beat of this tiny red beadlet, for it is the beginning of the activities of life. There is no

brain then to feed, there are no lungs to supply the blood with oxygen, but the little heartlet knows what is to be and begins to beat.

The amount of blood in the whole body is about 9 pints, and the amount of blood forced out of the left ventricle at each contraction, while a man of average size is at rest, is about $2\frac{1}{2}$ pints per minute, but during moderate exercise the left ventricle can pump five times as much, while an athlete's left ventricle during violent exercise can pump out blood at the remarkable rate of more than $8\frac{1}{2}$ gallons per minute or 60 times its own volume, meaning that both ventricles together must pump away at the rate of 17 gallons a minute. To supply its own muscles with food and oxygen sufficient for its own work, in the last case, the heart must pump into the arteries of its own walls about 5 pints of blood every minute.

When we consider that the heart weighs only half a pound, that it is no larger than a man's fist, the working power of the heart is amazing. An active man can raise himself 2,000 feet in an hour; but the heart does work every hour sufficient to raise itself 6,000 feet. In twenty-four hours it raises 32 tons, or 144,600 times its own weight, a foot high. While the work done by the heart of a healthy man in five months would suffice to raise it out of the gravitational field of the earth; and the work done by a healthy heart in seventy years would suffice to fling itself more than two million miles.

As the blood circulates under the drive of the heart a steady pressure is maintained in the aorta, and on this pressure life and health depend. It can be measured by tying a glass tube in the aorta and measuring the height to which a column of blood rises in the tube. Normally the pressure is great enough to lift a column of blood to a height of 64 inches above heart-level, but it varies, even in health, with the requirements and the state of the tissues; it

can be increased or reduced, firstly, by increasing or decreasing the rate of the heart-beat and the volume of blood discharged on contraction, and secondly, by enlarging or narrowing the calibre of the small arteries (arterioles) which open into the capillaries. The pressure is not under the control of the will but is regulated automatically in several ways. It is regulated by nerves which convey messages from the heart to that part of the spinal cord known as the *medulla,* and provoke the medulla in turn to send messages back to the heart, either through a nerve called the "vagus," which slows down the heart, or through nerves called "sympathetic," which accelerate it. It is regulated by the constitution of the muscle itself, for, even after all nerves to the heart have been cut, it is found that when more blood is sent to the heart, e.g., by contraction of the muscles of the body, the heart expands and beats more strongly. It is regulated by the contraction of little cuffs of muscle round tens of thousands of arterioles. The little cuffs act as stop-cocks which are automatically turned on and off as required. When a muscle is in action all its hundreds of stop-cocks are automatically opened, and other stop-cocks, such as those regulating the supply of blood to the digestive organs, may be closed. "Every time we alter our posture," writes Sir Arthur Keith—"when we lie down, stand up, or sit upright—there is a silent and automatic switching of the tens of thousands of vascular stop-cocks in the body," and fainting is often due to a breakdown of the stop-cock machinery allowing the blood to drain away from the brain. Blood pressure is also regulated by nerve messages sent during excitement to the little bodies above the kidney called "adrenals," which, thereupon, throw into the blood a substance called "adrenalin" which stimulates the closure of the stop-cocks of the arteries of the abdomen.

The average rate of the heart is from 60 to 75 beats

a minute; but rates faster or slower are quite compatible with health, and it is notable that, except during active exercise, the hearts of fine athletes beat often very slowly—sometimes as slowly as 45 times a minute. Napoleon's heart, it is said, beat at a rate of only 40 times a minute.

Though the heart is stimulated and repressed by outside nervous, chemical, and thermal influences, its rhythmic beat is an innate quality of its own constitution: it is the result of an *automatic* contraction of the thousands of tiny muscular fibres of which it is composed and the contraction, as we have noted above, begins when the heart in the embryo is less than a pin's head in size. It begins then, and all through life it never ceases, and the only rest the cardiac muscles enjoy is the momentary pause between the heart beats. Even if the heart be cut out of the body, it continues to beat for days if it be supplied with food and oxygen, and Alexis Carrel has actually fed strips of excised heart muscles and kept them beating for months.

The purpose of the heart is to propel the blood, and the blood is a very marvellous fluid. It is the intimate flowing environment on which all the phenomena of life depend. There are only about nine pints of it, but they fill thousands of miles of arteries, and veins, and capillaries, and every year convey to and fro some thousands of pounds of nutrient and some thousands of pounds of waste material.

When we analyse the wonderful red fluid, we find that it consists of water with certain particles in suspension in it and with certain substances—proteins, sugar, salts, gases, etc.—in solution.

The particles in suspension are chiefly red and white blood cells, and it is the red cells that give blood its red colour. The cells are microscopic, and in a drop of blood about the size of a pin's head there are about 5,000,000 red cells, and about 20,000 or 30,000 white.

The red cells are tiny biconcave discs consisting of

a sponge-like substance surrounded probably by a thin membrane. Seen singly under the microscope they look yellow; but seen *en masse,* in their millions, they make the blood seem red, or purplish. They measure only $\frac{1}{3200}$ of an inch in diameter and about $\frac{1}{12000}$ in thickness. It is these red corpuscles which collect oxygen as they are driven through the lungs, and it is the colouring matter, "hæmoglobin," in them which holds on to the oxygen. In the arteries, when the colouring matter has plenty of oxygen in its grip, it is called "oxyhæmoglobin": the oxygen gives it a brighter colour, and hence arterial blood is specially scarlet.

The colouring matter has the largest molecule of any known organic substance, and it is the only organic substance in the body that contains iron in its composition. It is the iron in the pigment that gives it its colour, and Ruskin asks: "Is it not strange to find this stern and strong metal mingled so delicately in our human life that we cannot even blush without its help." The red cells are so numerous and so small that they may be said to be ubiquitous, and they carry oxygen along the capillaries to every single cell, in every nook and cranny of the tissues. The capillaries of the lung, as we have said, put end to end would stretch across the Atlantic, and, altogether, the capillaries represent thousands of miles of tubing, yet the red cells are more than sufficient to fill every inch of them. Their number gives them an enormous aggregate surface. The red cells of a man put flat, single deep, edge to edge would cover an area of more than 3,300 square yards, or a pavement a foot wide and 6 miles long. Arranged shoulder to shoulder in single file they would stretch more than 200,000 miles—more than two-thirds of the way to the moon; while the red blood cells of the whole human race would suffice to cover the whole globe with a red carpet. Since a red blood cell lives only about a fortnight there must be

a constant production of new ones, and if all the red cells formed by a man during a lifetime of seventy years were put in single file they would reach more than three times to the sun.

The red cells are made in the red marrow of the bones, and, when their life is done, they are broken up in the liver, which uses the iron in them to colour its bile green or golden.

The white cells, or leucocytes, though not so numerous as the red cells, are larger and livelier. They have an average diameter of $\frac{1}{2500}$ of an inch, and they do not merely float passively like the red cells in the blood stream, but are able to crawl and slither about. In appearance and behaviour they are akin to the common *amœba proteus* commonly found in ditch water. There are various kinds of white cells, differing in size, staining properties, etc., but we cannot detail these here.

The functions of the white cells are numerous. Metchnikoff showed that they devour and digest microbes; they remove foreign bodies; they manufacture and throw into the blood various useful substances; sometimes they devour the pigment of the hair and the lime of the bones. The white blood cells live only a few weeks, but new ones are constantly made in the spleen and the lymphatic glands.

Besides red cells and white cells, little granules, called "blood-platelets," are also found suspended in the blood.

These, then, are the particles in suspension in the blood; let us now look at the substances in solution. In solution there are all the mineral salts of the sea, fats, soaps, sugars, uric acid, albumin, globulins, and extractives. There is also in solution an important substance called "fibrinogen" which, under certain circumstances, causes coagulation of the blood. Without "fibrinogen" we should be liable to bleed to death on very slight provocation.

The blood also contains protective substances, such as *immune* bodies, *complements,* and *anti-toxins,* which destroy microbes and neutralise *toxins.*

There seem to be three main ways in which the blood opposes microbes. The phagocytes may eat them; the immune bodies and complements may destroy them; the anti-toxins may neutralise the microbic toxin.

The blood, then, is not merely a carrier of food and oxygen and waste material, but performs various other important functions.

## CHAPTER IV

### *RESPIRATION—THE LUNGS*

WE have already indicated the important part played in the vital environment of the cell by the oxygen of the air. Without both air and food the linked processes of building up and breaking down, on which life depends, cease, for the cell lacks both material and energy to "carry on."

As in the case of food, elaborate measures have to be taken to bring the oxygen into intimate environmental relationship with the compact cells of the body. As in the case of food, too, adequate environmental relationship is achieved mainly by means of the heart and circulation. The red cells loitering through the capillaries of the lungs pick up oxygen from the air in the air-cells of the lungs and transport it to the remotest corners of the body, so that every cell has its *quantum*. Much oxygen is required, and, even as abundance of oxygen is brought to the combustibles of a furnace by a furnace bellows, so abundance of oxygen is supplied to the red cells loitering through the lungs by an application of the bellows principle. The lungs, indeed, are just two super-bellows whose bag is worked by the expansion and contraction of the musculo-bony wall of the chest under which they lie. The elastic bags of the lungs follow—and *must* follow—the up and down movements of the chest wall, and expand when the chest cavity enlarges, and contract when the chest cavity contracts.

The bellows mechanism of the chest walls and lungs is ingenious and effective. The ten upper ribs of the chest, which, with the chest-bone, make a series of hoops enclosing the chest contents, are curved bones hinged to the vertebræ of the spine behind and attached by prolongations of gristle or cartilage to the

breast-bone in front. They are not placed horizontally like the Equator, but hang down obliquely from their spinal hinges like the ecliptic, and by a little alteration of their obliquity, by making them more or less horizontal, the chest-bone attached to them in front can be carried up and down. When the ribs are lifted upwards into a more horizontal position, it is obvious that the chest-bone is carried upward and outward, and that the cavity of the chest is enlarged both in an antero-posterior and lateral direction; while if the ribs fall into a more oblique position, the chest is flattened and its cavity decreased. Such movements of the ribs and chest-bone are effected by muscles. The muscles which raise the ribs and render the rib-hoops more horizontal are called the *external intercostal.* They pass from rib to rib, and their common *point d'appui* is the backbone. The muscles which depress the ribs and make their plane more oblique are the *internal intercostal,* which also pass from rib to rib, and the big abdominal muscles. The *point d'appui* of all these depressor muscles is the bony rim of the pelvis. The ribs and breast-bone also tend to fall merely from their own weight and from the inward pull of the elastic tissue of the lungs.

The bellows action of the cavity of the chest is increased by the movements of a muscular floor named the "diaphragm," which partitions the cavity of the chest from the cavity of the abdomen. This, as Sir Arthur Keith has pointed out, may be considered as a muscular hood over a piston composed of the tense abdominal contents—liver, stomach, spleen, etc. As the chest expands, the muscular cap flattens out, pushing the piston down, thus still further increasing the size of the chest cavity, while as the ribs fall and the chest contracts, the diaphragmatic muscles relax, its cap bulges again, and a contraction of the strong abdominal muscles pushes the visceral piston up into the chest cavity, thus further reducing its area. The

chest is thus a bellows fitted with a piston to increase its efficiency—a packed piston composed of the abdominal viscera " which the diaphragm and muscles of the belly-wall use as a shuttlecock with each breath we take and give." In forced breathing many auxiliary muscles can be called into play. " Man," says Sir Arthur Keith, " has not yet conceived a design which can rival or approach the respiratory bellows."

The lungs, then, are a very perfect, ingenious pair of bellows, so constructed as to draw in and to expel air with great efficiency; and all through life these wonderful bellows suck in and blow out air sixteen or seventeen times a minute, and thus bring considerable volumes of oxygen into contact with the red cells in the capillaries of the lungs. But ingenuity to fit the respiratory apparatus for its vital functions does not end there, and we find at every point ingenious adaptations to an end.

The air drawn into the lung bellows when they expand passes through the nostrils to the throat. In the nose the chill is taken off it by scroll-like little radiators heated by a flux of warm blood, and at the same time it is moistened by the moisture in the nostrils, while the colder and drier the air, the more heat and moisture is added to it *en route*. Air entering at 14° F. below freezing leaves the nose at a temperature of 77° F.; and air entering dry leaves the nose saturated. Not only is the air heated and moistened, but the germs are caught and killed by the sticky fluid mucus, secreted over the crooked course of the nasal passages. Air containing thousands of microbes on entrance to the nose contains few or none when it enters the throat. The entrance to the throat is guarded also by the tonsils, which, too, trap and kill germs.

Both air and food pass through the back of the mouth into the throat; and the openings of the œsophagus for food, and of the trachea for air, lie side by

side, and so to prevent food from going the wrong way, there is a little leaf-like lid, the *epiglottis,* which can close temporarily over the opening of the trachea as the food is swallowed. A little lower than the epiglottis, the air passes through a slit-like narrowing of the trachea, called the *glottis,* which contains the two vocal cords—cords capable of adjustment at various distances from each other, or of closing altogether and shutting out irritating vapours. At the bottom of the trachea the air is drawn into the tubes called the *right* and *left bronchi,* into which the trachea bifurcates; and thence into the lungs.

The lung bellows are not simply bags; they are constructed in such a way as to provide a large surface of contact between the air and the blood. The two bronchi divide and subdivide, growing smaller with each division till they become almost microscopically minute. Then they expand a little into elongated sacs or *infundibula* indented and dimpled over their interior. The deep dimples bulge as convexities on the outer wall of the infundibula, so that, seen from the outside, they resemble bunches of microscopic grapes. The dimples are the air-cells, or *alveoli,* and over the outside of the infundibula are spread fine networks of capillaries, whose red cells collect oxygen from the air sucked into, or diffusing into, the air-cells. Infundibula and blood-vessels are bound together by a fine, stringy, elastic fibre known as connective tissue into the substance and *lobe*s of the lung.

All the air-tubes except the final divisions are lined with a sort of mosaic of cells like closely packed jars or cartridges, and the free surface of each cell where it abuts into the tube has fine hair-like prolongations called *cilia,* which are in constant lashing movement, and lash in such a way as gradually to shift mucus and foreign particles upwards towards the throat. The air-tubes have a smooth, glistening lining and are lubricated by mucus and secretion like white of egg.

The lung substance, consisting in a large degree of tiny hollow cells and bloodvessels, contains thus considerable quantities of moving air in contact with considerable quantities of flowing capillary blood. Altogether there are about 6,000,000 air-cells in the lungs, offering, when expanded, a total surface of more than 150 square yards, and capable of holding about a gallon of air at the same time, while, as we pointed out in the previous chapter, the capillaries, if joined together in one straight tube, would reach across the Atlantic, and the red cells in the blood offer a total surface of over 3,300 square yards. So we may say that a river thousands of miles long brings 3,300 yards of red blood-cell surface bit by bit into contact with moving air over a surface measuring more than 150 square yards. By the time the capillaries of the lung have been filled thirty times with blood, some 100,000 square yards of blood-cell surface have had an opportunity to take up oxygen from a surface measuring 4,500 square yards. Professor A. V. Hill has estimated, too, that during hard work six or eight times as much blood flows through the lungs, and that on such occasions the lung capillaries may hold 400,000,000,000,000 red cells.

These figures are bewildering, and, of course, very rough provisional estimates, but they at least show with what ingenuity and success Nature has achieved contact between the oxygen in the air and the cells of the body.

As soon as the red cells have completed their circuit of the body from left ventricle to right ventricle, they are redriven by the right ventricle through the lung capillaries to replete their depleted store of oxygen.

Let us now look more closely at some of the results of the bellows action of the lungs. The exact volume of air inspired and expired depends on the rate and extent of the respiratory movements, but in an adult man of average age, size, and vigour the volume is

about 500 cubic centimetres. This volume is called the *tidal air,* for normal expiration of this volume of air still leaves behind it in the lungs about 3,000 cubic centimetres of air which is called and considered *stationary* air. Half of the stationary air can be expelled by forced expiration, and this half is called the *supplemental* or *reserve* air; while the final 1,500 cubic centimetres which no effort can expire is called the *residual* air. Any air inspired over and above the *tidal* air is known as complemental and may amount to 1,500 cubic centimetres or more.

The total volume of air which can be expired after forced respiration is known as *vital capacity.*

Now let us consider more fully the biochemical significance of this able flow of air in the lungs.

The main purpose of respiration, as we have explained, is to bring to the cells the oxygen requisite for vital functions; but even as the circulation not only brings food to the cells, but also removes waste products, so, too, the tidal air not only brings oxygen for use of the cells, but removes waste in the form of carbon-dioxide. Briefly, the inspired air gives oxygen to the venous blood in the capillaries over the air-cells, and the expired air takes carbon-dioxide from the venous blood in the capillaries over the air-cells.

The following table shows in a general way the gaseous interchange in the lungs between air and blood:

| | *Volume per cent. (approximate) at 0° C.—760 mm.* | | |
|---|---|---|---|
| | *Oxygen.* | *Nitrogen.* | *Carbon-dioxide.* |
| Inspired air ... | 21 | 78 | ·03 |
| Expired air ... | 16 | 78 | 4·3 |
| Blood reaching the lung ... | 8 to 12 | 1·2 | 46 |
| Blood after exposure to air in the lung... | 20 | 1·2 | 40 |

If the pressure of any gas in the atmosphere is greater than the pressure of the same gas in the blood, then the gas in the atmosphere must pass into the blood even as carbonic acid under pressure passes into aerated soda-water. And again, if the pressure of any gas in the blood is greater than the pressure of the same gas in the blood, then the gas will pass from the blood into the air even as carbonic acid escapes from aerated water when the cork is drawn and the pressure reduced.

Now, the pressure of the carbon-dioxide in the venous blood of the air-cell capillaries is greater than the pressure of carbon-dioxide in the air of the air-cells, and therefore it passes from the blood into the air of the air-cells, and thence, by a process of diffusion, mixes with the general air in the lungs and atmosphere.

Again, the pressure of oxygen in the air of the air-cells is greater than the pressure of the oxygen in venous blood of the air-cell capillaries, and therefore the oxygen passes from the air in the air-cells into the venous blood.

That principle explains the interchange of carbon-dioxide in the air-cells of the lung, but it does not entirely explain the taking up of oxygen by the blood, for difference of pressure would account only for ·65 per cent. of oxygen in the blood, whereas arterial blood takes up no less than 20 volumes of oxygen. This difference is explained by the fact, already frequently mentioned, that the oxygen of the air enters into loose chemical combination with the hæmoglobin of the red cells.

The oxygen merely taken into solution by difference of pressure would not suffice to maintain life, and were the red blood-cells filtered from the blood a man would die of suffocation as if strangled. In the same way a man will die of lack of oxygen if his red cells are poisoned by carbon-monoxide and rendered incapable of combining with oxygen.

Respiration is thus a complex function involving processes of inspiration and expiration, diffusion, gaseous solution, chemical combination, and circulation. The oxygen inspired in the tidal air diffuses through the "stationary" air to the air-cells, thence passes into the blood, partly by solution and partly by combination, and then is carried to the cells of the body by the blood currents. The carbon-dioxide formed by the cells of the body is carried by the blood to the capillaries of the air-cells, thence passes out of solution into the air in the air-cells, and thence, diffusing into the tidal air, is discharged at expiration. It may be noted further that between the air and the blood are interposed the capillary walls, which probably play an active part in the interchange of gases, especially in the absorption of oxygen.

The air respired not only gives oxygen to the blood and removes carbon-dioxide; it also collects, and on expiration abstracts, heat and moisture from the tissues. By the time the air has been to the air-cells and back again, it is heated to the temperature of the body and saturated with moisture.

As we have already said, the oxygen is sent to the cells because oxygen is necessary to give the cell protoplasm its energy and maintain its structure. Likewise, the removal of a certain amount of the accumulating carbon-dioxide is necessary, for that gas in certain small proportions is the normal stimulant of the respiratory centre, and this proportion must be preserved. Nature takes care that all the carbon-dioxide should never be quite cleared out, and the residual air is a reservoir containing under ordinary respiratory conditions just the right amount of carbon-dioxide to provoke respiratory activity.

As a general rule the absorption of oxygen and the discharge of carbon-dioxide proceed *pari passu,* and the carbon-dioxide expired may be considered a measure of vital activity. Though breathing is, to

some extent, under the control of the will, yet it is maintained apart from volition and is constantly and mainly under the automatic control of a nerve centre—the respiratory centre situated near the top of the spinal cord—a centre which responds in the most varied and sensitive manner to chemical messages and nervous impulses proceeding from all parts of the body, and adjusts the working of the lung bellows to the needs of the organism. Thus when a man performs violent muscular exercise, his output of carbon-dioxide greatly increases, and if its discharge does not keep pace with its formation, an excessive proportion in the blood will stimulate the respiratory centre to more active work and thus also promote its own elimination. Not, however, the carbon-dioxide, but the lactic acid formed by muscular activity, is the main stimulant of the respiratory centre during active and prolonged muscular activity.

But the reflex adaptability of the respiratory mechanism is shown in a hundred ways. A douche of cold water makes one gasp. The sun makes one sneeze. Fear takes away the breath. And so on.

# CHAPTER V

## *BONES AND MUSCLES*

There are in the body 200 separate bones weighing together about twenty pounds. In the form of rods, and nodules, and platelets, made of phosphate and carbonate of lime, they give shape and meaning to the muscles attached to them, maintain posture, facilitate mobility, and protect vital parts. They are at once levers, *points d'appui,* and shields. Only with the assistance of bones can the voluntary muscles of the limbs fulfil their various functions. Without bones to act as mechanical instruments and supports, man would be as helpless as a jelly-fish. Without bones to protect his brains and spinal cord and heart, he could not survive, and, indeed, to bones the whole great class of vertebrata owe their existence.

For the various purposes they subserve, the bones are very efficient instruments beautifully and ingeniously constructed. Most of them are prefigured in cartilage—the skull-bones in membrane—and in the cartilage the lime is deposited by millions and millions of bone-building cells, and finally deposited in such a way as to enable the bone to continue growing during the period of growth, and also in such a way as to give it great strength and elasticity. In the long limb bones strength and elasticity are achieved by constructing them as hollow cylinders and by making their ends of an open resilient texture. The work of the little cells, the *osteoclasts* and *osteoblasts,* is most amazing. Millions of cells creep and crawl about, clearing away old rudimentary bone to make place for new finished bone, putting arches, and buttresses, and girders, and struts just where they are needed. There is no foreman, no master builder, no architect; they have no connection with the nervous system to direct them, and

yet they build the bone according to specification, and, having built it, they lie in millions in little spaces in the bone tissue in order to keep it in good condition and repair. They do all their work to time, too. At a definite date they begin certain bits of work, and at a definite date complete them. More wonderful still, if a bone be cut out but the membrane or *periosteum* surrounding it left, the osteoclasts and osteoblasts in the periosteum will proceed to make more bone. "I have that man's thigh-bone in my surgical collection," once remarked Dr. Joseph Bell as the man walked briskly into Edinburgh Infirmary. He had removed a diseased thigh-bone, and the wonderful osteoblasts and osteoclasts had made a new one.

A bone must not be considered as dead. Not only is it inhabited by millions of encloistered cells, but arteries, and veins, and lymphatics, and nerves run in all directions through it, and in its spaces are born the marvellous red blood-cells. More than two hundred small arteries enter the lower end of a thigh-bone.

Occasionally bone formation fails. Lacking a vitamin, called *Vitamin A,* which is contained in cod-liver oil and milk, and is also manufactured in the skin by ultra-violet light, the bones become soft and misshapen. In another disease called *osteomalacia,* the bones, originally well made, lose their lime and soften, while in the condition called *acromegaly* the bones of the face, hands, and feet in adult life grow disproportionately large. This last condition (and probably *giantism* also) is due to disease of a small gland at the base of the brain called the *pituitary gland.*

We have said that there are 200 bones altogether. Of these there are 26 in the backbone, 22 in the skull, 64 in the upper limbs, 62 in the lower limbs; and there are besides 24 ribs. In the hand alone there are 24 bones.

Some of the bones—as, for instance, the bones of the skull—are fixed immovably together, but most of

them are hinged together by movable joints. The ends of the jointed bones are covered with thin cushions of cartilage, and they are bound to each other by bands and cords of tough white fibres known as ligaments. The ligaments are so disposed as to permit free movement in useful ways and yet are so strong that it is often easier to break a bone than to dislocate it. The apposed cartilaginous surfaces are smooth, and glossy, and elastic, and their movements upon each other are rendered smoother through a lubricating fluid called *synovia.* It is interesting to note that the synovia is made of the dissolved substance of dead cartilage builders. As Sir Arthur Keith puts it: " When a cartilage builder is sacrificed on the altar of duty, it does not become withered and dry like the scales of the cast-off scarf-skin, but becomes soft and slippery, its body is turned into *synovia*—the oil or lubricant of joints."

The bone joints are of various kinds. The feet joints are ball and socket joints, where the end of one bone is ball-shaped, and the ball fits into a cup-like cavity in an adjacent bone. The shoulder joints and hip joints are of this kind, and, thus jointed, the upper-arm bone and the thigh-bone can be rotated to some extent on their long axis as well as moved in every radial direction. Other joints are hinge joints that allow bones so jointed to swing like a door on its hinges. Such joints are seen in the joints of the jaw and elbow. There are also gliding joints, allowing bones to slide to a certain extent on each other. Such joints are seen in the small bones of the wrist and foot. At the top of the spine, between the two bones called the *atlas* and *oxis,* there is a pivot joint which allows rotation in a horizontal plane for a certain distance as a watch-key is turned in its key-hole, while between the atlas and the skull there is a modified ball and socket joint. In every instance the joint is made in such a way as to permit of useful movements.

The relationship between bones and muscles is intimate, and, regarded from its mechanical aspect, is chiefly the relationship between a lever and the force working through it—the bone serving as an instrument to apply and multiply force and to modify in one way or another rapidity of movement.

Mechanics recognise three kinds of levers: (*a*) with fulcrum between weight and power, (*b*) with weight between fulcrum and power, (*c*) with power between fulcrum and weight. All these three kinds are represented in the bone-muscle system. In the case of the ankle joint, the power is exerted through the Tendo Achilles at the heel, and the fulcrum is at the fore part of the foot, where it presses on the ground, while the weight is at the ankle between. It is a lever of the second order. When we forcibly flex the forearm, it is a lever of the third order, for the power (exerted mainly at the insertion of the biceps muscle is the *radius*) is between the fulcrum (at the elbow) and the weight (at the hand). When we forcibly straighten the forearm, on the other hand, a lever of the first order comes into play, for the fulcrum at the joint is between the force and the weight. Most muscular actions are leverages of one kind or other, and the leverage used is of the kind most suited for mechanical efficiency in the particular work to be done.

There are 520 muscles in the body, weighing, in an average man, about 60 lbs., and so representing nearly half of his body weight. All consist of much modified cells which have been prolonged into fibres and straps and are bound together into bands, and sheets, and bundles. The fibres have a remarkable property of contracting and shortening and so pulling on any bone or other part of the body to which they happen to be attached, and the pose and the posture as well as the movements of the moving parts of the human body depend on their action.

One hundred and forty-four muscles go to the

balancing and bending of the spine. Twenty muscles are required to balance and move the head. The lower limbs require one hundred and eight. Every time we walk, hundreds of muscles are set in motion. In most cases muscular contraction of any muscle is associated with relaxation of others, and co-ordinated contractions and relaxations of many muscles are necessary for the performance of all purposive actions.

In another chapter we have dealt with the most remarkable of the muscle fibres of the body—the muscles of the heart. These have peculiar functional and structural characters; they contract without external stimulus by virtue of their own molecular constitution; they have a special microscopic structure of their own. These remarkable muscle fibres we shall not discuss further, and will confine our attention here to the other muscles found in the body.

Functionally there are two great classes of muscles—*involuntary* muscles, such as the muscles of the stomach and iris, outside the control of the will, and *voluntary* muscles, such as the biceps, which, under normal conditions, the will entirely or mainly controls; while a third class may be formed to include muscles such as the muscles of respiration, which usually work automatically, but can be influenced by the will. The contractions of all these three classes of muscles are fundamentally the same, but there is a microscopic difference between the voluntary aad involuntary, for the voluntary show alternate cross-bands of light and dark tissue (like black and white draughtsmen piled alternately on each other), giving them a striped appearance, while the involuntary are homogeneous. Microscopically the muscles of respiration belong to the voluntary class; and the muscle fibres of the heart, though different in shape, also show striping. What exactly the cross-stripings signify is unknown.

We cannot here discuss all the mechanical effects of muscular contraction, but in general, when a muscle

contracts, it fixes or turns various bones upon its hinges or balances the body, or moves skin or cartilage, or compresses or propels the contents of sacs and cavities. In the eye, muscular contractions alter the size of the iris and the curvature of the lens.

A muscle fibre is a thin thread about $\frac{1}{500}$ of an inch in diameter (probably of some fluid consistence), and even in a tiny muscle thousands of these are bound together into one bundle attached at their ends. In a well-developed biceps there are more than half a million muscle fibres, and it is the simultaneous contraction of them that gives the complete muscle its power. The muscle is richly supplied with capillaries and lymphatics, and each fibre has its own nerve fibril. A great part of the energy of the digestion, respiratory, and circulatory systems is expended in supplying the muscle fibres with food and with energy. Round each little muscle fibre there is a constant circulation of sugar and oxygen.

Though muscle fibres will contract on stimulation, even when their nerves are paralysed, yet the contraction of all muscles, except the heart muscle, is normally set in motion by nerve discharges, of which we shall have more to say in another chapter. In the case of the voluntary muscles, the discharges are set in motion by the will, but the whole further elaborate complex that brings into play the right muscles to the right extent is inherent in the nerve constitution, and quite automatic. It is possible, however, to excite discharge in any nerve without intervention of the will by stimulating or irritating it by chemical, electrical, or mechanical means.

The nerve impulse runs down each fibril that goes to each tiny muscle fibre, and as a result of the impulse the muscle fibre contracts. Why it contracts or how exactly it contracts we do not know, except that the contraction is in some way due to a regrouping and re-arrangement of the molecules of the fibre, and

that the energy is not derived, as used to be supposed, from oxidation, but in some way derived from the breakdown of a sugary substance (*glycogen*) in the muscle. The breakdown of glycogen throws lactic acid into the muscle. A man running rapidly for a hundred yards may produce an ounce of lactic acid. The energy derived from such a breakdown can be easily measured, and it is known that when one gram of glycogen is degraded into lactic acid, 235 calories of heat are set free, representing enough mechanical energy to lift 1 cwt. to a height of 6,528 feet; so that we have obviously in this chemical change a source of the energy of muscular contraction.

After contraction comes relaxation, and it has been found that during relaxation carbon-dioxide is formed in the muscle and considerable heat generated. The carbon-dioxide is not a product of oxidation or combustion, but is displaced from bicarbonate salts in the muscle by the newly formed lactic acid, while the extra heat generated is the result of this chemical change. The heat produced by the neutralisation of the lactic acid by the carbonate amounts to 135 calories for each gram of lactic acid neutralised. This one gram of glycogen breaking down in the muscle can give rise altogether to 370 calories.

Up to this point there is no oxidation (no combustion), but after the muscle has completed its work, oxidation to supply new energy and to convert waste substances takes place. A sixth of the lactic acid in the muscle is burnt up by the oxygen in the muscles (taken from the red blood-cells in the capillaries), and reduced to carbon-dioxide and water, and with the energy thus obtained the remaining five-sixths of the lactic acid are built up into glycogen again. In this way the muscles can use some of their glycogen over and over again. The muscles meantime are also absorbing glucose from their capillaries, and, with the aid of insulin sent them by the pancreas, are changing

it into glycogen. According to Professor A. V. Hill, a man at work can be supplied with a gallon of oxygen a minute by seven gallons of blood pumped through his heart in the same time.

We see, therefore, that oxygen is necessary to maintain a supply of energy in the muscle cells, and up to a point, the heart and respiration, by working harder, can oxidise the extra lactic acid and can restore the store of energy as quickly as completed. The matter is clearly explained by Sir Arthur Keith in his book *The Engines of the Human Body*. But at a certain point oxidation fails to keep pace with the formation of lactic acid, and the lactic accumulates in the muscles, and may go on accumulating till it forms $\frac{1}{300}$ of their total weight. Beyond that point accumulation cannot go, for at that point the muscles will act no longer.

Whatever amount of lactic acid accumulates in the blood during exercise constitutes an oxygen debt, for until enough oxygen has been taken in to burn and convert the accumulated lactic acid the man is handicapped and liable to be quickly exhausted. Hence, after violent exercise a man pants in an effort to increase his oxygen supply.

The muscle, thus fed and thus energised, is a wonderful machine; but, like all machines, it fails to transform all its energy into mechanical work, and the physiologists calculate that its efficiency is only 25 per cent. The best triple expansion engines can utilise only about 12 per cent. of the potential energy of coal, gas engines 14 to 25 per cent. of the potential energy of gas, so that the muscle as a machine is more efficient than a steam engine, and about as efficient as a gas engine. Moreover, a piece of muscle weighing only 15 grains can lift a weight of 60 grains to a height of 13 feet, and consume in its work less than a thousandth part of its substance.

According to Professor A. V. Hill, the biceps and brachialis anticus muscles of a fairly muscular man

can exercise a force of about 2,000 lbs., yet these muscles weigh only half to three-quarters of a pound, and are made of a jelly-like material.

Fatigue, like exhaustion in a muscle, is due to accumulation of lactic acid and to reduction of its store of energy. If we inject lactic acid into a fresh muscle, it at once gives indication of fatigue, while if we wash the lactic acid out of a fatigued muscle the fatigue disappears.

When a muscle in man is stimulated it waits for $\frac{1}{400}$ of a second before it contracts; it takes $\frac{4}{100}$ of a second to complete its contraction, and about $\frac{5}{100}$ of a second to complete its relaxations; so that in human muscles not more than ten twitches a second can be produced, and if we try by rapid electrical stimulation to obtain more we produce, not separate contractions, but one long continuous contraction. Try as we may, we cannot move any muscles—even finger muscles—faster than ten times a second. In this respect insects far surpass us. A fly can vibrate its wings 335 times a second, and a bee 440 times. But we can at least beat the tortoise, which sometimes cannot manage to make more than two or three contractions per minute.

During life all muscles, voluntary and involuntary, are in a state of slight tonic contraction due to a rapid continuous stimulation through their nerves. The vigour of these little involuntary contractions varies from time to time. The limp feeling produced by a hot bath, or by hot weather, is largely due to an actual slackening of the muscles, while the braced-up feeling produced by a cold bath or a cold breeze or a dose of strychnine is largely due to an actual tightening of the muscles. When we feel slack we really are slack.

As we have already noted, the processes of muscular contraction and restoration produce heat, and in the muscles, especially during active exercise, a great part of the heat which maintains the warmth of the body

is formed. This, therefore, may be a convenient place to consider the factors that make and regulate the temperature of the body.

The amount of heat produced by active exercise may be very great. Dr. Leonard Hill found that swimming increased the heat more than twelve-fold the rate of his own combustion. He found, too, that a soldier weighing 154 lbs. and carrying a pack weighing 68 lbs. produced every five minutes sufficient heat to raise the temperature of his body one degree. Were there no means of escape for the heat produced, his temperature at this rate of increase would reach boiling point within nine hours. The liver, too, is a fierce furnace, and all the chemical processes of digestion produce heat.

There is therefore plenty of heat to boil the body, and the wonder is not so much that it is hot as that it usually maintains a steady temperature of 98° F. to 99° F. How is this effected?

The supervisor of the bodily temperature is the skin, which contains all over it little meteorological nerve stations which transmit messages to the brain and spinal cord, which again send nervous messages to regulating mechanisms. The regulating contrivances are various. Probably the most important are the capillaries of the skin. In the capillaries of the skin the blood is near the surface, and its heat readily radiates away, and so by a regulation of the amount of blood in the capillaries it is possible to control the escape of heat. When, then, the body becomes unduly hot, messages to this effect are sent by the observatories in the skin to the brain and spinal cord, and the brain and spinal cord at once open the stop-cock muscles of the arterioles supplying blood to the skin capillaries, so that the blood floods the skin and gets cooled there. When, again, the surface of the body becomes too cool, the nerve watchers in the skin inform the brain and spinal cord, and in this case they close the stop-cocks

and prevent so much of the blood from reaching the skin and becoming cooled there. We see evidence of these processes in the red face of a hot man, and in the pale face of a cold one.

Another very potent regulating device is the sweat-gland apparatus. When the body becomes unduly hot and the brain and nervous cord are made cognisant of the fact through their agents in the skin, they may not only flood the skin with blood, but also send messages provoking the sweat-glands to action, and the evaporation of the sweat abstracts a great amount of heat from the surface. This device is most effective if the air is hot or dry, for then evaporation takes place readily and rapidly. It is much less effective if the air be damp, and it is ineffective if the air be saturated with moisture. Not only does this cooling device fail in damp air, but damp air conducts heat much more rapidly to the tissues. Hence in a hot, moist atmosphere heat stroke is common.

When the body is long exposed to cold it often develops fat, which is a non-conductor, in order to conserve its own heat, and it is possible that the thyroid gland in the neck, whose secretion in some mysterious way promotes combustion, may be more active during exposure to cold.

In all these ways the body succeeds in maintaining a steady temperature, usually between 97° F. and 99° F.

If, in spite of all contrivances, or through their breakdown, the bodily temperature rise much above 105° F., death usually follows.

# CHAPTER VI

## *THE NERVOUS SYSTEM AND BRAIN*

THE nervous system consists essentially of millions and millions of microscopic cells (situated chiefly within the skull and spinal canal), whose molecular changes give rise to sensation and thought, and, propagated by long branches, initiate and control most of the chemical and mechanical occurrences in the body.

The spinal nerves in their cellular context may be taken as typical of the nervous system.

Seen by the naked eye, a spinal nerve is a white glistening cord of varying size, and, examined microscopically, is found to consist of a tight compact bundle of hundreds of long, straight fibres, each about $\frac{1}{2000}$ of an inch in diameter (*i.e.*, $\frac{1}{10}$ the diameter of a fine human hair), and each surrounded and insulated by a sheath of phosphorised fat called *myelin* and covered by a delicate membrane.

Tracing these fibres—say, from a finger—up towards the spine, we discover that they emerge from the spinal canal as two separate bundles, one anterior and one posterior, and that the two bundles amalgamate soon after emergence. The anterior bundle is called the *anterior root;* the posterior the *posterior root,* and if we trace the fibres of each we discover some interesting facts.

If we follow a fibre of the anterior root into the spinal cord, it is found to be a branch of one of a group of cells in the spinal cord, and the cell is found to be grasped (as if by fingers) by the branched end of a long fibre descending within the spinal cord from the brain. Every fibre in the root has similar connections; thus the finger is brought into relationship with

the brain by a long nerve tract arranged in two relays. Further, on stimulating by an electric current any part of this nerve tract in connection with the finger, it is found that impulses pass down the nerve in a direction from the brain to the finger and cause contraction of a muscle fibre in the finger; but that no impulses can be sent in the opposite direction up to the brain. The fibres are normally stimulated by molecular changes in the cells, whose branches they are, and because the impulse passes *from* the brain and causes motor changes in the muscles, they have been called *motor* or *efferent* fibres. When I wish to move a finger, molecular disturbances in cells in my brain are propagated through long fibres descending in the spinal cord to other cells in the cord, and the cells in the cord send impulses down long fibres which end in the muscles of the fingers and stimulate them to contract. The motor cell in the cord is thus a mediator between the brain and more peripheral parts, and the efferent impulse is like a telephone message with two relays.

Now let us look at the fibres in the posterior root. On tracing and dissecting one of these fibres, it is found to be the two long arms of a bifurcate fibre which belongs to a cell in a little swelling (*ganglion*) on the root itself. One arm goes down the spinal nerve to amalgamate with the efferent fibres of the spinal nerve, and proceeds in a direction away from the spine, while the other arm enters the spinal cord and proceeds up it to the brain stem, and thence, by relays, is connected with cells in the grey matter of the brain. The cell in the posterior root is like a man standing with extended arms. When we stimulate the fibres or cells of the posterior root, no direct motor movement follows, but impulses pass upwards along the spinal cord to the brain and give rise to sensations. Because these fibres of the posterior root pass towards the brain and cause sensations they are called

afferent or sensory fibres. If I prick my finger, these fibres send impulses to the cells in the posterior root, and these cells transmit impulses to the cells in the brain.

We see, therefore, that a spinal nerve contains nerve fibres of two kinds—efferent or motor, and afferent or sensory.

The long nerve arms, which are usually called *axons,* are undoubtedly outgrowths from the cell with which they are connected, and if a nerve is cut, the cell, under favourable conditions, will grow again to its old length, much as a hair bulb grows out new hair when hair is cut. A nerve may even be cut and its new sprouts "trained" in a new direction, so as ultimately to be a medium of impulses to and from tissues with which normally it is unconnected. In this way important muscles, whose nerves have been paralysed, may be given a fresh nerve supply; and cases of facial paralysis have been cured by bringing to the facial muscles a nerve which normally innervated shoulder muscles.

Besides axons, nerve cells have usually numerous shorter crooked branches called *dendrites;* and the dendrites of adjacent cells intertwine, and, even though there is no actual junction, seem to be a means of intercellular communication.

Impulses passing from their cells down motor or efferent nerves have other results besides exciting muscular contraction; some cause glands to secrete, some inhibit movement, some promote nutrition. Some very fine afferent fibres—not spinal, but belonging to a special system called the sympathetic system—help to regulate involuntary muscle contractions. Other efferent fibres, along with the so-called *cranial* nerves of special sense, come directly from the brain and from the bulb of the brain, and regulate the secretion of the pancreas, salivary and other glands. It is rhythmical impulses from efferent nerves, sent out all

through life at a rate of from forty to eighty a second, that maintain the normal tone of the muscles.

Impulses going towards the brain along the afferent nerve tract sometimes appear in consciousness as sensations of heat, or cold, or hardness, or pain, but sometimes they do not appear in consciousness at all. Many of the afferent impulses that appear in consciousness start in nerve-endings in the skin.

The most important and interesting of all afferent nerves are the nerves of seeing and hearing and smelling and tasting.

So far we have spoken of the afferent and efferent impulses as if they were independent, isolated, and self-contained. But there is probably no such thing as isolated afferent and efferent impulses. Every afferent nerve as it passes brainward along the spinal cord gives off branches that embrace and excite the cells of efferent fibres in the cord, and all afferent impulses when they reach the brain also excite the efferent centres there. Every afferent impulse, indeed, is contained in spinal cord, or brain, or both, as efferent impulses which initiate or modify physiological processes in the body.

When the efferent impulse is involuntary it is known as *reflex* action. Thus if my foot be tickled, the afferent impulses excite efferent motor centres which in turn excite involuntary movements. Since the reflex moves muscles, it is called an excito-motor reflex. Again, if I smell appetising food my mouth waters. This also is a reflex, for it is excited by the afferent nerves of smell, and since it causes secretion it is called an excito-secretory reflex. These are conscious and well-known reflexes; but other unconscious involuntary reflexes go on constantly and play essential parts in the vital functions and in vital behaviour. Thus when we close our fingers, the muscles which extend the fingers are relaxed by reflex action. When we get too hot, the "stop-cocks" in the

arteries governing the blood supply to the skin are opened by reflex action. When we stand, the right motor discharges are sent to the muscles by reflexes excited by afferent impulses from the soles of the feet. All through life there are thousands of millions of unconscious reflexes taking place. The main object of the millions of cells and axons and dendrites in the spinal cord and brain seems to be to link together afferent and efferent impulses in such a way that afferent impulses produce processes and actions useful to the individual and render as many processes and actions as possible independent—in detail at least—of the will. The will merely wishes: the reflexes carry out the wish. Not merely muscular movements and actions but most of the processes that go on in the organs of the body—heart, lungs, liver, kidneys, spleen, etc.—are beautifully and subtly initiated and regulated by afferent impulses which excite just such answering efferent impulses as result in processes good for the organism.

The nerve system is indeed " an extraordinary collection of millions of cells and millions of fibres all acting and reacting in thousands of co-operative groups—efferent impulses answering afferent impulses with the wisdom and prescience of a Solon, with a delicate physico-chemical ingenuity no Faraday or Kelvin could emulate, and with results as amazing as all the functions, and feelings, and thinkings of a man. . . . Little groups of them are looking after the bloodvessels. Little groups of them are engaged in watching the breathing. Little groups of them are engaged in balancing and performing other complex co-ordinated movements. Little groups of them under very mixed and complex afferent impulses from the eyes and joints and cerebal cells are moving pens across paper. Little groups of them are translating the molecular excitement produced in them by afferent

impulses initiated by invisible waves of ether or air —are translating their excitement into colour, and beauty, into sound and music. Little groups of them it was that, under the influence of environmental stimuli, made Shakespeare think and Shakespeare write. The intricacy and multitudinousness, the delicacy and precision of the network of cells and fibres, of discharging stations and receiving stations, baffle the imagination."

It is impossible to prophesy the results of an afferent impulse; it may be like a spark to gunpowder, like a finger on a trigger. A slight pressure on the cerebral motor cells may cause an epileptic fit; a few black marks on a telegram may move a man from London to New York.

In a general way, the higher the organism the more complicated will be his nerve cell relationships, and the more far-reaching will be afferent impulses that reach his mind. One may see the lid of a kettle jumping under steam pressure and think only of a tea-pot. Another man may see the same leaping kettle lid and have a vision of a locomotive.

Here an interesting question arises. Do the conscious sensations which often follow afferent impulses depend for their character on the nature of the original stimulus, or on the nature of the afferent nerve, or on the constitution of the cerebral nerve centre which the impulses finally reach?

Helmholtz believed that if we could interchange the nerves of seeing and hearing and fix the end of the auditory nerve to the eye and the end of the optical nerve to the ear one might see thunder and hear lightning, and Helmholtz was probably right, for a nerve whose normal function is to send slowing impulses to the heart was grafted on another nerve which dilates the pupil, and on stimulating the grafted nerve the pupil was found to dilate. Again, the vibrations of a tuning fork held on the skin

are felt as vibrations while the ear hears them as sound. Again, flame is known to the fingers as heat and to eye as light. So it would seem that the effect in consciousness of any afferent impulse depends entirely on the percipient cells in the brain and not at all on the axons carrying the impulse, or on the stimulus originating it.

Like all the other tissues of the body, the nerve cells and nerve fibres require food and oxygen, and the blood supply to the brain cells is particularly pure and abundant, being carried almost directly from the heart carotid and vertebral arteries. The spinal cord is also well supplied with blood. We do not yet know what food substances the nervous tissue specially requires and specially selects from the blood. The nerve tissue, however, breaks down very little in the course of its impulsive changes, and seems to need little food, and can flourish even on a restricted dietary. But we know that it requires abundance of oxygen, and that if oxygen be deficient the mental powers fail. On the other hand, if quite cut off from oxygen, the nerves use up all oxygen at hand, and die within ten minutes, so that in cases of drowning a man cannot be brought back to life again even if—as is often the case—the heart and lungs are alive.

The impulses that pass along the nerves and excite other tissues of the body are obscure in nature. The rate at which they travel—400 feet a second in man and 100 feet or less a second in frogs—shows that they are not electrical waves, for electrical waves travel 186,000 miles a second. Professor A. V. Hill believes that the impulse is partly chemical and partly electrical, or "a wave of electro-chemical change." Its chemical side is shown in the rise of temperature which is found to follow excitation, and the electrical side is shown by the little waves of electro-potential which can be detected when a nerve is stimulated.

The chemico-physical constitution of nerve matter must be very unstable up to a certain point at least, for even an infinitesimal amount of scent affects the smelling centres, and the touch of a hair on the big toe is instantly felt in the brain. Even the afferent impulses sent by a tooth cutting the gums may provoke afferent impulses to the muscles sufficiently violent to cause convulsions.

So far we have dealt only and incidentally with the most wonderful part of the nervous system—the brain—but though here we have not space to discuss it properly, yet it demands a few special words.

The brain, which is an enlargement and prolongation of the spinal cord, lies within the skull wrapped up in several coverings. On removing the coverings it is seen to be composed in the main of three parts—the cerebellum, and the right and left lobes of the cerebrum. Its surface is much furrowed and fissured, so that it shows convoluted folds known as the convolutions of the brain. When it is examined microscopically it is found chiefly to consist of an outer layer known as the *grey layer,* composed of millions and millions of nerve cells surrounding white matter composed of nerves going in all directions. The grey matter seems to be the seat of volition and intelligence, and is more plentiful in the more intelligent races; but there does not seem to be any direct relationship between size of brain and mental ability.

Within the last sixty or seventy years certain faculties and motor centres have been located in definite areas of the brain. In 1861 a French physician named Broca demonstrated that an area in the convolution of the brain known as the *third left convolution* was the motor centre of speech, and a few years later Fritsch and Hitzig found in the frontal region of the brain of dogs areas concerned with the co-ordinated movements of their limbs. To-day we have mapped out in the human brain the motor cells

which move the toes, ankle, knee, hip, shoulder, fingers, thumb, arm, leg, eyelid, jaw, and other parts, and know that the left side of the brain controls the right side of the body, and *vice versa.* We know, too, where the centres of sight, hearing, smell, touch, and taste are situated.

There are still, however, parts of the cerebrum whose function we do not know. We do not know, for instance, the function of the convolutions immediately behind the forehead. They are frequently particularly well-developed in clever men, and have therefore been supposed to be the seat of some of the higher faculties, but there is little or no proof of this.

The cerebrum as a whole must, nevertheless, be considered the seat of the intellect, for the complicated network of cells and fibres which compose its grey matter is certainly in some way the basis of memory, of abstract conceptions, of ideas, and the volitional initiation of movements.

As a motor centre the brain is not supreme; it merely wills certain movements, it does not itself perform them; and its volition represents merely a molecular disturbance in certain cerebral cells—a disturbance which, propagated to the cerebellum and spine, incites centres there to send out co-ordinated impulses productive of the necessary muscular contractions. The muscular contractions are further regulated and stimulated by efferent impulses following afferent messages from the muscles, joints, skin, inner ear, and other parts participating in the movement or affected by it.

The cerebellum at the base of the cerebrum is a special centre for the co-ordination of complicated muscular movements, and if the cerebellum is diseased there is muscular weakness and staggering gait. The motor-cells in the cerebellum, however, that assist in the preservation of equilibrium are regulated and stimulated to due action by afferent mes-

sages from the skin, and eyes, and muscles, and joints, but especially from the semi-canals—three semicircular tubes filled with fluid and set in three different planes in the internal ear. As these tubes change position with movements of the head and body the movements of the fluid within them excite afferent nerves connected with them, and the excited nerves send messages to the cerebellum and provoke from it suitable messages to the muscles concerned with equilibrium.

In a sense the skin may be considered a part of the nervous system; it is true that it performs functions of excretion, secretion, and protection that have not much connection with the special functions of that system, but, on the other hand, the tactile, thermal, and other nerves which terminate in the skin render it at once a great reflex centre, and a great source of conscious experience.

A great part of the proper function of the brain consists, not in sending forth volitional motor impulses, but in giving emotional and intellectual significance to afferent impulses reaching it from the special senses and skin, and of co-ordinating them in consciousness.

We have not space here to deal adequately with the great sense organs, but before leaving the subject of the nervous system we must devote a few words to the two greatest—the eye and the ear.

The eye consists essentially of a receiving nervous surface, the *retina,* which, under the stimulus of light, sends afferent impulses to the nerve centres of sight at the back of the cerebrum. This nervous surface is spread over the back of the interior of a hollow ball—the eyeball; in front of the eyeball is a little circular disc of transparent tissue, the cornea, which admits light to its circular chamber. Round the margin of the little corneal window is a narrow circular rim or curtain of contractile tissue, by means

of which the "window" area can be enlarged or diminished. The curtain may be of various colours, blue or grey or black or green or brown. Behind the "window" and the "window curtain" again is a transparent elastic biconvex lens which focuses light on the retina. Filling the chamber of the eyeball is a jelly-like substance known as the *vitreous humour.* The eyeball is set in a bony cup or socket, and can be moved in various directions by muscles attached to its exterior. Further, it is guarded by two eyelids fringed with eyelashes, and is kept moist and clean by water poured over it from the lachrymal gland.

The lens of the eye is of a very remarkable character. It is contained in a little translucent bag which exactly fits it, and by means of little muscles, the *ciliary* muscles, its curvature can be altered, and so it can be adapted to focus light from objects near and far.

In the normal eye, when the ciliary muscles are relaxed the lens focuses light from distant objects, while in order to focus light from near objects the ciliary muscles must contract and render the lens more convex. This alteration in the curvature of the lens is known as *accommodation* and is a purely reflex movement. With increasing age the lens becomes less elastic and more rigid, and so cannot be sufficiently curved or bulged to focus very near objects. A child can see objects plainly at four inches distance, a man of forty will usually not be able to see objects clearly at a nearer distance than nine inches, and must hold a book at this distance in order to read small print. This condition is known as *presbyopia,* and can be relieved by the employment of biconcave lens to augment the curvature of the natural lens of the eye.

When the eyeball is too long from before back, parallel rays of light from distant objects are focussed, even with the lens relaxed, in front of the retina, and

are seen "out of focus," and we have a condition known as *short-sight,* or *myopia.*

When the eyeball is too short from before back, near objects are focussed even with the lens fully curved further back than the retina, and so are seen "out of focus" with indistinct, blurred, outlines. Such a condition is known as *long-sight* or *hypermetropia.*

When the curvature of the lens is not uniform, vision is contorted, and we have a condition known as *astigmatism.*

Astigmatism, myopia, and hypermetropia can all be relieved by suitable glasses.

The retina is an intricate and complex tissue consisting of innumerable cells and fibres arranged in twelve layers. The deepest layer, which is in connection with the optic nerve, is the most important. It is made up of cells like rods and cones standing together side by side, and is therefore sometimes known as the "layer of rods and cones." The rods and cones transmit to the optic nerve the impulses evoked in them by the waves of light—impulses that eventually reach the cells in the sight centres of the brain and finally appear in consciousness as light and colour and other visual sensations.

The rods contain a purple pigment known as *visual purple,* and this pigment doubtless plays a part in the chemical processes of the nerve-cell impulse. It is bleached by exposure to light, but is quickly formed again.

There are said to be three million rods and even a greater number of cones in the retina of man, and there are probably about five hundred thousand fibres in the optic nerve.

The sensations of colour which arise in the consciousness as a result of waves of light stimulating the retina vary with the rapidity of the waves of light. The slowest, longest waves of light give rise to

the sensation of red; the quickest, shortest waves to the sensation of violet; and waves of intermediate length give rise to the other colours of the rainbow.

Thomas Young and Helmholtz propounded a trichromatic theory of colour vision. They suggested that there were three different kinds of cones in the retina—one kind producing the sensation red, another kind the sensation violet, and yet another kind the sensation blue. Other colours they believed to be produced by stimulation in varying proportions of the three rods, and white they believed to be produced when all three kinds of rods were equally stimulated. Another theory of colour vision suggests that there are six primary colours, black, white, red, green, yellow, and blue.

The organ of hearing is as wonderful as the organ of seeing, and even more complicated. It consists essentially of an extension of the auditory nerve, and of apparatus to transmit to it certain vibrations of the air.

The leaf-like flap of the ear collects the sound waves so that they pass through a tube an inch long and impinge on a delicate membrane called the *drum* of the ear, or *membrana tympani*. Within the membrana tympani is a bony cavity, the *middle ear*. Across the cavity three tiny bones form a kind of chain, attached on the one hand to the membrana tympani, and on the other hand to another membrane, the *fenestra ovalis,* which is applied over an opening in a coiled bony tube (like a snail's shell) called the *labyrinth*. Fitting exactly into the labyrinth is a membranous bag, the *"cochlea,"* containing a fluid in which are immersed the terminations of the auditory nerve. The vibrations of the membrana tympani are conveyed across the inner ear by the chain of ossicles to the membrana of the labyrinth, and the consequent vibrations in the latter membrane cause changes in the pressure of the fluid in which the terminations of

the nerve of hearing are immersed. These terminations, like the strings of an Æolian harp (though infinitely more numerous), differ in their character, respond differently to the various vibrations of the fluid, and send various differing impulses to particular cells in the hearing centre of the brain, and hence arise in the consciousness various sound sensations.

The inner ear contains also the "semicircular canals"—the three semicircular canals concerned with balance, which we have already mentioned.

The mechanism and anatomy of the internal ear are very complicated and intricate and cannot be adequately described here.

The nervous system, especially the brain and the special senses, is the most important part of the bodies of the higher animals, and in man all the work of the digestion, respiratory, circulatory, glandular, and muscular systems seems to find its significance and summation in the conscious mind—in sensation, thought, feeling, and memory.

## CHAPTER VII

### *ORGANS AND GLANDS, LIVER, ETC.*

An organ may be defined as a conglomeration of tissues, structurally distinct, and, in a measure, separate from the rest of the body, which performs special mechanical and chemical functions useful for the organism. Those organs whose special function is secretion are classed as glands.

Some organs we have already described—the heart which propels the blood, and the lungs which are collecting-centres of oxygen, the brain with its motor and sensory cells and fibres, and the digestive organs which prepare food and fuel for the cells of the body, while in connection with the latter we have mentioned various glands. There remain still several organs and glands which we must briefly discuss.

The largest and heaviest organ in the body is the *liver.* It lies in the upper part of the abdomen, tucked under the lower ribs of the right side. Microscopically it consists of little bunches of cells, each about the size of a pin's head. The bunches are tightly packed, giving the liver a firm, compact structure. Through the substance of the liver runs the portal vein, which conveys the blood from the abdominal viscera to the heart. Dividing into two branches as it runs, it forms a fine framework of capillaries for the lobules. The capillaries are imperfect, and the blood actually oozes out so that the cells are given a blood bath.

Functionally the liver is a gland of great chemical activity: every cell is a busy chemical laboratory. One chemical function of the busy organ is to form bile, a yellowish-greenish fluid, containing 86 per cent. water and 14 per cent. solids. The solids consist of bile salts

known as sodium glycocholate and sodium taurocholate, together with cholesterin mucin pigments and inorganic salts.

The bile is collected from the cells of the liver by little tubules and reaches the surface by a duct, the hepatic duct, which soon divides into two branches—one leading to a little reservoir, the gall-bladder, where bile can be stored between meals for use, and one opening directly into the desodernum. The liver pours out about two pints of bile a day.

Bile has little or no digestive action on carbohydrates and proteins; but it dissolves fatty acids, and by moistening the walls of the intestine facilitates the passage of the fat through them. In the absence of bile, fat is poorly digested and absorbed.

When there is any obstruction to the passage of bile, it enters the blood and colours yellow the skin and mucous membranes.

But the secretion of bile is quite a minor accomplishment of the liver. Its most important function is to manufacture from the glucose, carried to it by the portal vein, a starch-like substance called glycogen. This glycogen it stores to convert it into glucose again and send it to the tissues in accordance with the tissues' need of it. After a carbohydrate meal, 12 per cent. of the weight of the liver consists of glycogen.

Under conditions of starvation and hard work, all the liver's reserve of glycogen may be quickly depleted, but, as a rule, the liver cells manage to keep a "balance in the bank." If more glucose is carried to the liver than the liver can convert and the tissues use, then a certain amount of sugar is discharged in the urine—a condition known as alimentary diabetes or alimentary glycosuria. This is not a serious condition, and is easily remedied by dietetic measures. True, diabetes is due not to excess of sugar, but to disease of the pancreas, and is a much more serious matter. We have already seen what an important part is played by the

pancreatic juice, which, as an external secretion, the pancreas pours into the intestine. But it also manufactures another substance which does not reach the exterior through a duct, but, as an *internal* secretion, is thrown directly into the blood which circulates in the interior of the gland. It is lack of this internal secretion which is the cause of true diabetes. Lacking this internal secretion, the cells of the body are unable to assimilate glucose; it flows past them in the blood and is eliminated in the urine. The same internal secretion seems to assist the cells to oxidise fats, and, in its absence, poisonous fatty acids accumulate in the blood, and produce a dangerous condition known as *acidosis*.

Within the last few years Dr. F. Banting, of Canada, succeeded in extracting the internal secretion from the cells of the pancreas. It is now known as *insulin,* and given to patients suffering from diabetes, it enables their cells again to assimilate glucose.

Substances secreted by cells, which are thrown into the blood as internal secretions and affect the metabolism of the body, are called "hormones." Secretin is a hormone: insulin is a hormone.

The part played by insulin in the assimilation of sugar is one of the mysteries of life; but it is plain that it is in vain for the liver to manufacture glycogen and to throw glucose into the blood unless the pancreas is also doing its duty.

The liver not only manufactures bile and converts glucose into glycogen and reconverts glycogen into glucose; it also alters fats, so that with the aid of insulin the tissues can oxidise them, and builds up complex fats known as *phosphatides*. Further, it prepares amino-acid for use in the tissues by converting their nitrogenous portion into urea, and destroys excess of uric acid. So that altogether the liver plays a big part in the economy of the body.

The two *kidneys,* though not such large and

versatile organs as the liver, are still of vital importance. They are situated far back in the upper part of the abdomen, one on each side of the back. Each is about 4 inches in its greatest diameter, and is composed essentially of multitudes of long, coiled tubes; the tubes, by fine orifices, secrete a fluid known as urine into a duct, and the duct leads the urine into a hollow muscular sac called the bladder, whence it is discharged on the surface. Arteries enter the kidney and break up into capillaries, and during the passage of the blood, water and certain solids are abstracted.

The walls of the capillaries are very thin; the pressure of the blood is considerable, and a certain amount of simple filtration through the capillary walls into the tubules must occur; but the process is more than a process of simple filtration, for in health neither sugar (unless present in excess) nor albumin passes through, and urea is added to the fluid by actual excretion from the cells lining the tubules, and a substance called purpuric acid, which is not present in the blood, is added.

Healthy urine contains 1·2 per cent. of common salt, 2·0 per cent. of urea, 0·05 per cent. of uric acid, 0·07 per cent. of hippuric acid, no sugar and no albumin. Its colour is due to bile pigments. The most interesting solids are the urea and uric acid. Both are formed by the liver and the urea from amino-acids, the uric from the nuclei of broken-down cells. Uric acid in excess leads to the formation of gravel-stones and to the deposition of salts of uric acid in the cartilages of the joints.

The kidneys abstract, on the average, about 2½ pints a day from the blood—less or more, according to amount of fluid taken and according to the activity of the sweat glands. The solid matter in the fluid amounts to about 2 ounces a day.

The *spleen* is a little organ about the size of a closed fist, tucked up under the lower ribs on the left-

hand side. In structure it is like a fine sponge-work, and the intricacies of the sponge-work are packed with white and red blood-cells. It contains muscular fibres, too, which contract and relax and drive blood through it as if it were a little heart. It fulfils two or perhaps three functions. It destroys worn-out red blood-cells: it makes new white blood-cells: and it is possible that it also forms new red cells.

The *lymphatic glands,* like the spleen, have a sponge-like structure, and are packed with white cells, but they are not filled, like the spleen, with blood. They vary in size from a millet-seed to a bean, and are found in great numbers all over the body, but especially in the neck, groins, and armpits, and along the course of the great blood-vessels of the chest and abdomen. Their function is to form white blood corpuscles and to catch and destroy microbes. Sometimes microbes—especially the bacilli of tuberculosis—prove too strong for the lymph-glands, and they then swell and may break down and suppurate, as is often seen in the glands of the neck.

The *thyroid gland* is a soft gland which lies in front of the neck below Adam's apple. It consists of two lobes, right and left, connected by an isthmus. It is made up of little sacs lined with clear cells, inside which is a jelly-like material called *colloid.* Its blood supply is very plentiful.

The internal secretion or hormone of the thyroid stimulates old growth and development, including the development of bone: it also stimulates the processes of combustion in the body, and has an intimate relationship with the activity of the sexual glands. Because of its power of increasing combustion in the body, extract of thyroid gland is often used to burn up the excessive fat in obese people.

The diseases known as *myxœdema* and *cretinism* are due to inactivity of the thyroid gland, but luckily it was discovered that the gland, raw or cooked, could

be used to supply the deficiency of the thyroid hormone in these cases. The effect of thyroid extract in these diseases is marvellous.

In some cases the thyroid is over-active and throws too much hormone into the blood, and the result is a disease called *exophthalmic goitre,* or *Graves' disease,* with bulging eyes, great nervousness, rapid pulse, wasting, and muscular weakness. This disease can usually be prevented or cured by administering small doses of iodine, but its cause is still rather obscure.

Under the lobes of the thyroid are four little glands, a pair on each side called the *parathyroids.* Only within the last forty years have they been recognised as active and important agents in the metabolism of the body. In 1891 it was discovered that they were connected with the condition of spasmodic muscular contraction known as "tetany," and it is now believed that the convulsions of infants and "paralysis agitans" (trembling palsy) have some connection with impaired action of these glands. It is also believed that deficiency of the secretion from these glands plays a part in the disease called "osteomalacia"—a disease in which the bones become brittle and fragile.

When the four glands are removed, "tetany" occurs; the nutrition of the hair and nails suffers, and in some cases cataract of the eye is developed.

The *thymus gland* is essentially a gland of childhood. It is situated in the neck, lower down than the thyroid, and reaches its maximum size towards the end of the second year. After puberty it dwindles, and usually almost entirely disappears. It probably exercises an influence on the growth of the child and the development of the sexual organs, and there are disturbances in both respects if the thymus disappears too early or too late.

Very important and interesting glands of internal secretion are the two *supra-renal bodies,* set like nightcaps on the top of the kidneys. They are built up of

connective tissue, fibrous tissue, groups of cubical cells, bloodvessels, and altered nerve-cells. When these bodies degenerate, Addison's disease supervenes. This disease is characterised by a peculiar bronzing of the skin, great weakness, vomiting, and nervous prostration, and is always fatal. Experimental removal of the bodies is followed by death within twenty-four hours.

The supra-renal bodies manufacture and throw into the blood a very potent hormone called "adrenalin" (first isolated by a Japanese scientist, Takamine). A very minute injection of this hormone raises the blood pressure, and there can be no doubt that in normal conditions it maintains, or helps to maintain, the contractile tone of the arteries and of the voluntary and involuntary muscles. Adrenalin also makes the hair of the head to stand on end, dilates the pupil, causes a flow of saliva, and in a general way stimulates the sympathetic nervous system.

Two more glands—the pituitary and the pineal—must still be noticed. The *pituitary gland,* about the size of a ripe cherry, lies within the skull attached to the base of the brain. In inner structure it is very like the thyroid, and it has two lobes, an anterior and a posterior. The hormone of the anterior lobe undoubtedly plays a part in the growth and development of bone. Excessive activity of this lobe in early life will so stimulate bone growth as to produce a giant, while excessive activity in adult years will produce the disease called "acromegaly," characterised by over-growth of certain bones, notably the bones of the lower jaw, hands, and feet. The hormone (called "pituitrin") of the posterior lobe, on the other hand, influences the reproductive system, raises the blood pressure, slows the heart, causes the contraction of various involuntary muscles, and increases the secretion of milk.

The *pineal gland,* about the size of a small cherry-

stone, is situated at the base of the brain behind the pituitary. It is really a prolongation of the substance of the brain, and is connected by nerve fibres with the centres in the brain which receive impressions from the eye and which move the eye-muscles. Indeed, it is believed to be the vestige of an eye, known as the "pineal eye," which is found in a more highly developed condition in certain lizards. It is certainly an amazing thing that a relic of this eye should have persisted through millions of years. Now, the gland has no optical functions at all, but it is believed to produce hormones connected with the sexual organs and with the growth of hair and bone; for tumour of its substance is associated with premature puberty, with precocious development of hair, and with abnormal growth of the long bones.

This brief consideration of the organs of the body at least serves to show how cell reacts on cell and hormone on hormone—to show how complexly inter-related are all the structures and functions of the body. The pancreatic hormone fails and the cells cannot assimilate sugar: the thyroid hormone becomes excessive and the eyes bulge and the heart races: the thyroid hormone becomes deficient, and we have a *cretin:* the little pituitary gland in the base of the skull works too hard and we have a giant. The human body can develop satisfactorily and work efficiently only if all its cells and organs are working in harmony, and there is no harmony more beautiful and more complicated than a healthy, active human body.

Generally speaking, our brief survey of the body has shown that it is a commonwealth of millions and billions of inter-dependent cells, supplied through the blood, driven by the heart, with food prepared in the digestive organs and with oxygen collected in the lungs, whose utilisation is assisted by many ancillary organs—a commonwealth whose structures and energies are co-ordinated and initiated and guided by that wonder-

ful system of cells and fibres called the nervous system, at whose head is the still more wonderful organ the brain, which—through a mind—can not only will many of the movements of the body, but translate some of its molecular movements into thoughts, emotions, and sensations.

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